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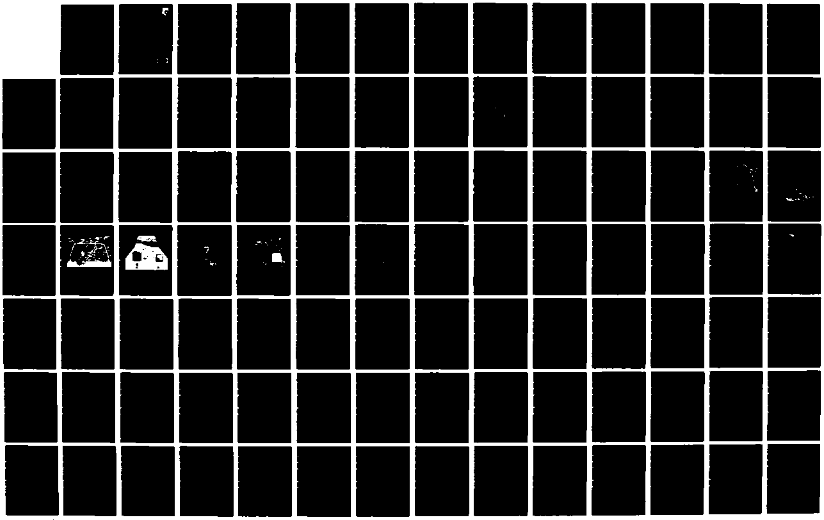

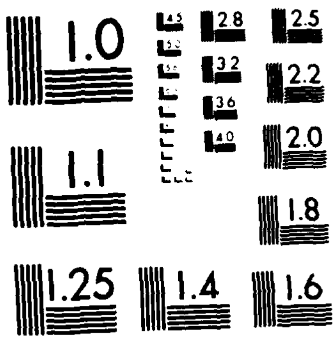

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AFWAL-TR-84-1016

DISPLAY TECHNIQUES FOR ADVANCED CREW STATIONS (DTACS)
PHASE 1 - DISPLAY TECHNIQUES STUDY

MCDONNELL AIRCRAFT COMPANY
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MARCH 1984

FINAL REPORT FOR PERIOD APRIL 1983 - OCTOBER 1984

AVIONICS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
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This technical report has been reviewed and is approved for publication.

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The DTACS Final Report describes the study which explored advanced display techniques and their effect on future fighter/attack aircraft crew stations. The emphasis was placed on new and developing technology with applications to integrated avionics systems. Future mission requirements were reviewed, display requirements were established, display technologies were reviewed, an initial configuration of an advanced display was made and a plan for further development was also prepared.

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PREFACE

This report covers work performed for the Air Force Wright Aeronautical Laboratories (AFWAL) under Contract F33615-83-C-1040. Mr. Noel Schwartz served as the project manager. The work was performed by the Advanced Crew Station Project Group, Advanced Engineering as prime contractor with Hughes Aircraft Company, El Segundo, California as subcontractor.

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DISPLAY TECHNIQUES FOR ADVANCED CREW STATIONS

FINAL REPORT

1.0 INTRODUCTION AND SUMMARY

This final report is submitted to the Avionics Laboratory, Air Force Aeronautical Laboratories AFWAL, by the McDonnell Aircraft Company (MCAIR), a division of the McDonnell Douglas Corporation (MDC) in accordance with contract F33615-83-C-1040 dated April 1, 1983. The report describes the results of a seven (7) month definition study to explore advanced display techniques and their innovative application to integrated avionic systems for future fighter/attack crew stations. The study established assumptions, reviewed requirements for displays and integration, and established simulation requirements to evaluate the concept.

Use of multipurpose displays has made contemporary fighter crew stations more versatile than ever before; however, these displays are not a panacea. Hardware limitations in terms of total display area, display bezel light plates, and supporting structure prevent bringing those independent displays together into a large single display. As a result, the pilot must spend a large percentage of his time managing the individual displays and mentally fusing the information presented on each. Thus, the incentive for this study comes from the growing complexity of fighter aircraft systems and missions, and the need to simplify the pilot's perceptual, information processing, and control tasks. Specifically, the following two conditions are evident:

1) The single most unrelenting pervasive problem in today's fighter is a lack of situational awareness, and

2) Pilot workload related to display control and information fusing is unacceptably high. This is a result of the pilot's effort to maximize display usage to improve his situational awareness. This condition is becoming even more acute because technologists are attempting to increase processing capabilities ten-fold even though we already produce much more information in our tactical aircraft than we can simultaneously display.

The root cause for both of these conditions is that existing cockpits with two or three multipurpose displays surrounded by supporting structure, knobs, switches, and instruments utilize the total instrument panel area inefficiently. A typical strike/fighter instrument panel has approximately 325 square inches of surface of which at best, only 80 square inches, or 25% is available for use during the fight. The other 75% is not available to the pilot for information on or about the enemy. The three multipurpose displays making up that 80 square inches are not large enough to effectively present "fused" data to the pilot. They are too small to simultaneously present both the range (coverage) and scale (resolution) required. Thus, although a tremendous amount of data is available, the display size limitation allows the pilot to see only isolated pieces of the data at any given time. The pilot's attempt to maintain situational awareness can be likened to viewing a wide screen movie through a pair of soda straws whereby he must constantly flick them around the screen to try and gather the "big picture".

Present aircraft configurations, illustrated in Figure 1, place the burden

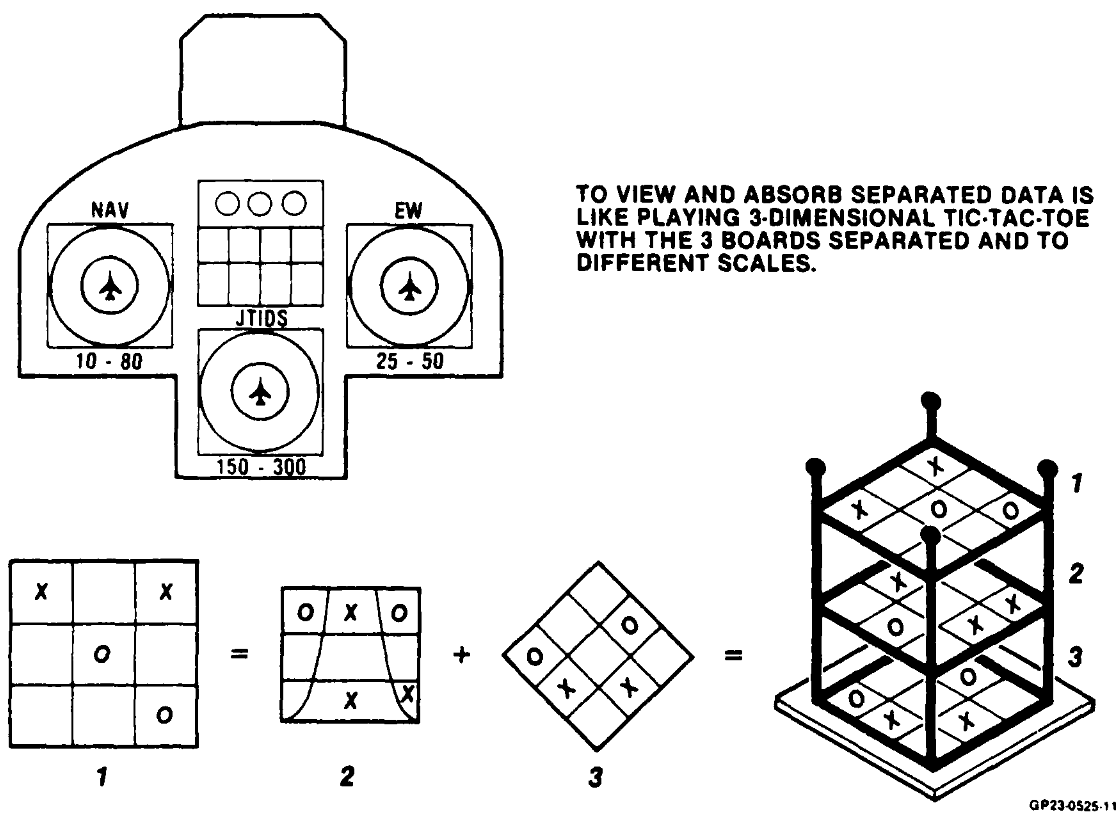


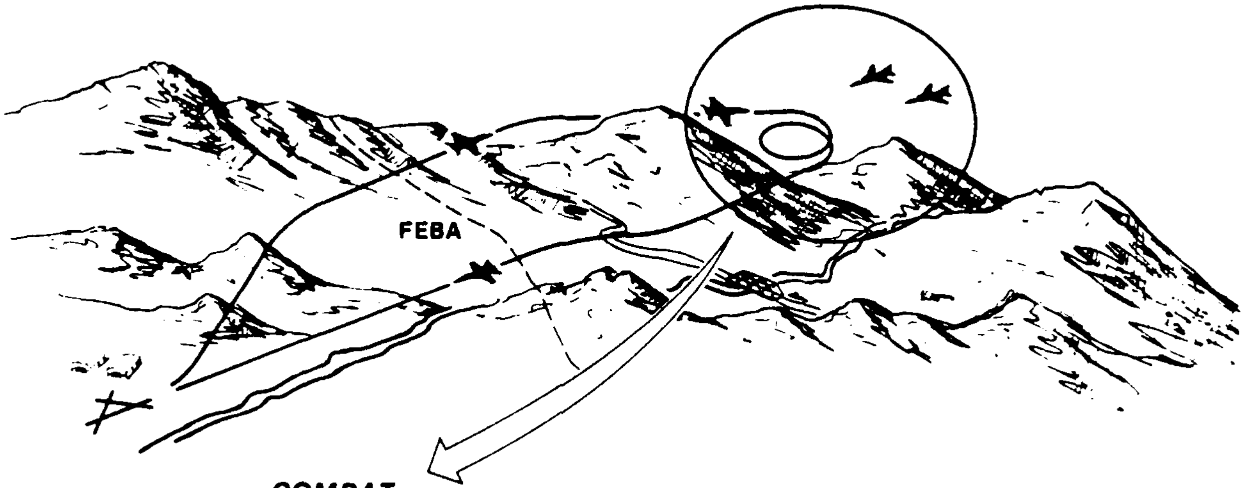
Figure 1. Data Fusion

of maintaining situational awareness on the pilot. He must initially choose to display one type of information on each of the multipurpose displays and must then manage the range/scale for each display based upon the information required. He mentally processes the information from all the displays to form a composite picture of the real situation. This is much like playing 3 dimensional tic-tac-toe except that the 3 boards are not neatly stacked for easy visual perception, but rather are laid out on a table top and are different sizes and at different geometric orientations. The results of the data processing, in either the aircraft or our theoretical game, are stored only in the "players" mind since none of the individual boards is suitable for the composite picture.

There are many more display formats than available display surfaces (Figure 2) Each display format has a different value to the pilot (depending upon the missior phase) and each format competes for one of the displays. The differences in form characteristics as well as the differences in range/ scale requirements limit the amount of data fusion which can occur on the present size multipurpose displays. Thus the pilot is really playing a multilayered tic-tac-toe game, but only a limited number of levels are viewable simultaneously.

The pilot of a modern tactical fighter spends much of his time managing the multipurpose displays; that is, choosing the source of the data to be displayed and selecting optimal range settings. He is constantly gathering data from the sources and at the ranges presently being displayed and wondering about data which might be available from another source or at a different range. He frequently changes display selections to gather as much information as possible. In addition he is constantly trying to evaluate data presented in varied formats and ranges. The entire operation can be aptly described as "fiddling and flying". The result is a high level of pilot workload directed at managing displays and correlating information, rather than using that information to obtain and exploit a tactical advantage.

The display size limitation also prevents data fusion due to valid considerations of display clutter. For example, when data is fused on small displays, targets or threats which are several miles apart in the real world begin to overlap. The symbols become hard to interpret or must be artificially relocated



COMBAT

DISPLAYS	CHARACTERISTICS
RADAR	FORWARD HEMISPHERE
IR	FORWARD/LOWER HEMISPHERE
EW	SPHERICAL
JTIDS	SPHERICAL
NAV/MAP	PLAN AND/OR ASPECT
HELMET DISPLAY	SPHERICAL
WEAPONS	PLANFORM
SYSTEMS	ALPHA/NUMERIC
— ENGINE	
— FUEL	
— AVIONICS	

- USUALLY DISPLAYED SEPARATELY
- PILOT MENTALLY CORRELATES (FUSES)
- COORDINATED ATTACKS CUMBERSOME

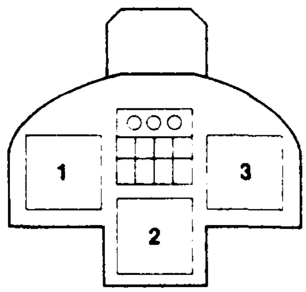


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Figure 2. Example Format Requirements

on the display to prevent unacceptable clutter, thus destroying the real world range and azimuth information.

The number of data sources is large and expanding rapidly (Figure 3) along with the complexity of systems. The small display size and the need for distinguishable symbology without clutter have forced designers to use hieroglyphic type symbols such as those shown in Figure 4 and 5. Use of these non-intuitive symbols forces the pilot to spend his time studying symbology instead of tactics. Any field updates to provide additional capability often add or redefine certain

DATA EXPLOSION!

- JTIDS
- ELECTRONIC MAPS
- MISSION PLANNING
- HIGH RESOLUTION SENSORS
  - RADAR
  - FLIR
  - TV
- GPS
- AUTO TARGET
  - RECOGNITION
  - CORRELATORS
- TACTICAL FLIGHT MANAGEMENT
  - AUTO TF
  - AUTO TA
  - AUTO WEAPON DELIVERY
  - CORRELATED ATTACK
- PICTORAL FORMATS
- PURPLE HAZE - EW/ECM
- HELMET SIGHT/DISPLAY
- VOICE RECOGNITION/WARNING
- WEAPONS
  - EO
  - IR
  - WASP
  - ROCKEYE
  - AMRAAM
  - WAM
  - ASSAULT

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Figure 3. Where Are We Going

symbols, creating stress for the operational community. Furthermore, the symbols which the pilot needs to recognize quickest in combat will be rarely seen during training and, in fact, the first time he sees the most critical symbols when airborne may be when it's for real.

The arrangement of the multipurpose displays as well as the physical constraints of supporting structure and lighting bezels limit the ability to have full control over assignment of display area. For example, there often is a requirement to make two or more sensor imagery comparisons and a requirement to show four simultaneous independent formats. A design could be made to solve either of these requirements, but not both.

Real display requirements vary in size and content throughout the mission. More flexibility is needed in terms of the number of independent formats which can be simultaneously displayed and the size and location of each to meet these varying requirements.

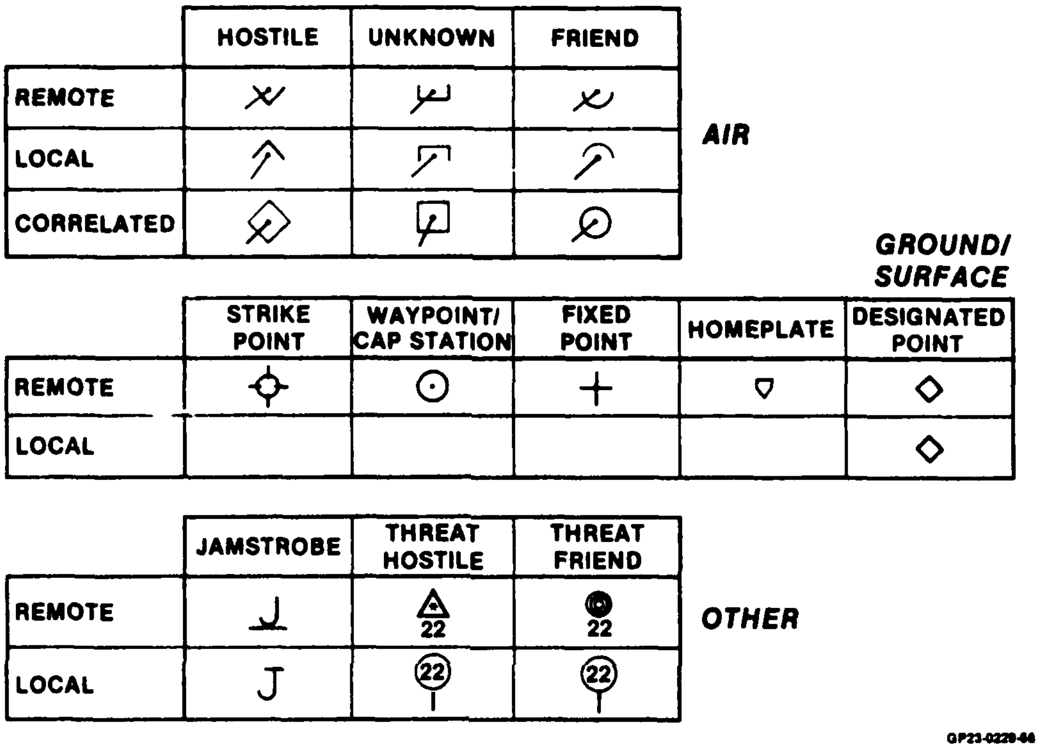

Figure 4. Basic JTIDS Symbology

Even the most modern fighter aircraft have over half of the area of the instrument panel inflexible and not contributing to the most critical mission related functions. While the formats on the multipurpose displays are programmable, the size and location of the displays themselves are fixed. When such a crew station design is delivered to the operational units, it must be "endured" for a long period of time because physical rearrangements are time consuming and very costly. Tomorrow's crew station design should include sufficient flexibility to allow incorporation of the latest subsystem advancements without costly and time consuming crew station changes.

The solution to improved situational awareness and reduced pilot workload will require innovative control and display concepts. Two possible solutions are shown

	SYMBOL	EXAMPLE
REMOTE ASSIGNMENT		
LOCAL ASSIGNMENT		
POINTER		
MACH AND ALTITUDE (1,000 FT)	1.1 25	1.1 25
CHALLENGE COMMAND	C	C
DESTROY COMMAND	D	D
PRIORITY KILL COMMAND	K	K
DISENGAGE COMMAND		
NCTR (AIR)	FILLED IN SYMBOL	
MULTIPLE TARGETS (AIR)	DOUBLE LINES	
OTHER USER ASSIGNMENT	o	
GROUND/SURFACE MODIFIERS — HOSTILE		
— UNKNOWN		
— FRIEND		

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Figure 5. JTIDS Symbol Modifiers

in Figure 6. The addition of more multipurpose displays would allow more simultaneous display of data and would reduce the amount of display switching workload. However, the small size of the displays would still force the pilot to mentally fuse the data. The addition of fewer but larger displays would allow some fusing of data with like formats (navigation, JTIDS, and EW) but would not totally relieve the pilot of that responsibility. Furthermore, a maximum of three simultaneous formats could be displayed, still requiring the pilot to switch between displays to gather more information. In actuality, the pilot, assisted by automated avionics, needs the capability to configure the display area in either of these ways if required.

The conclusion of this study is that essentially the entire instrument panel area should be used as a touch sensitive rear projection electronic display

I ADD DISPLAYS

- **HELPS SOMEWHAT BY ALLOWING MORE SIMULTANEOUS DATA DISPLAY**
- **PILOT STILL FUSES DATA MENTALLY**

II LARGER DISPLAYS

- **HELPS SOMEWHAT BY FUSING SOME DATA (NAV/JTIDS/EW)**
- **LESS SIMULTANEOUS DATA**
  - **SYSTEMS**
  - **WEAPONS**
  - **ENG/FUEL**
- **PILOT STILL FUSES DATA MENTALLY**

PILOT NEEDS THE FLEXIBILITY OF BOTH

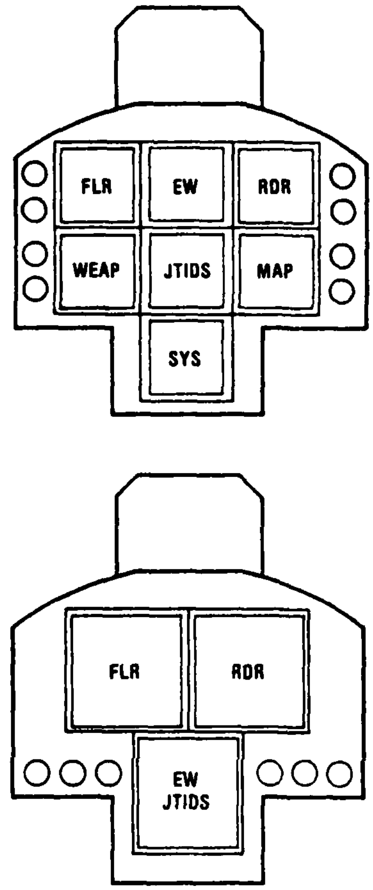

Figure 6. Instrument Panel Alternatives

device. This 300 square inch display would provide over ten times the present display surface area, allowing the pilot to effectively fuse mission data from all selected sources (Figure 7) without sacrificing either range or scale limited details. It will allow the use of pictorial symbology without clutter and will provide the flexibility to allocate various areas for as many independent displays as required by the pilot. The size and quantity of the displays could be tailored to meet any mission and any mission phase (Figure 8). In a similar IRAD effort at MCAIR, a wide angle Head Up Display (HUD), computer generated Voice Response (VR), Voice Recognition Control (VRC) and a Helmet Mounted Display/Sight (HMD/S) were included in the concept to extend the crew interface features and provide the pilot with a means for unprecedented "situational awareness" and control.

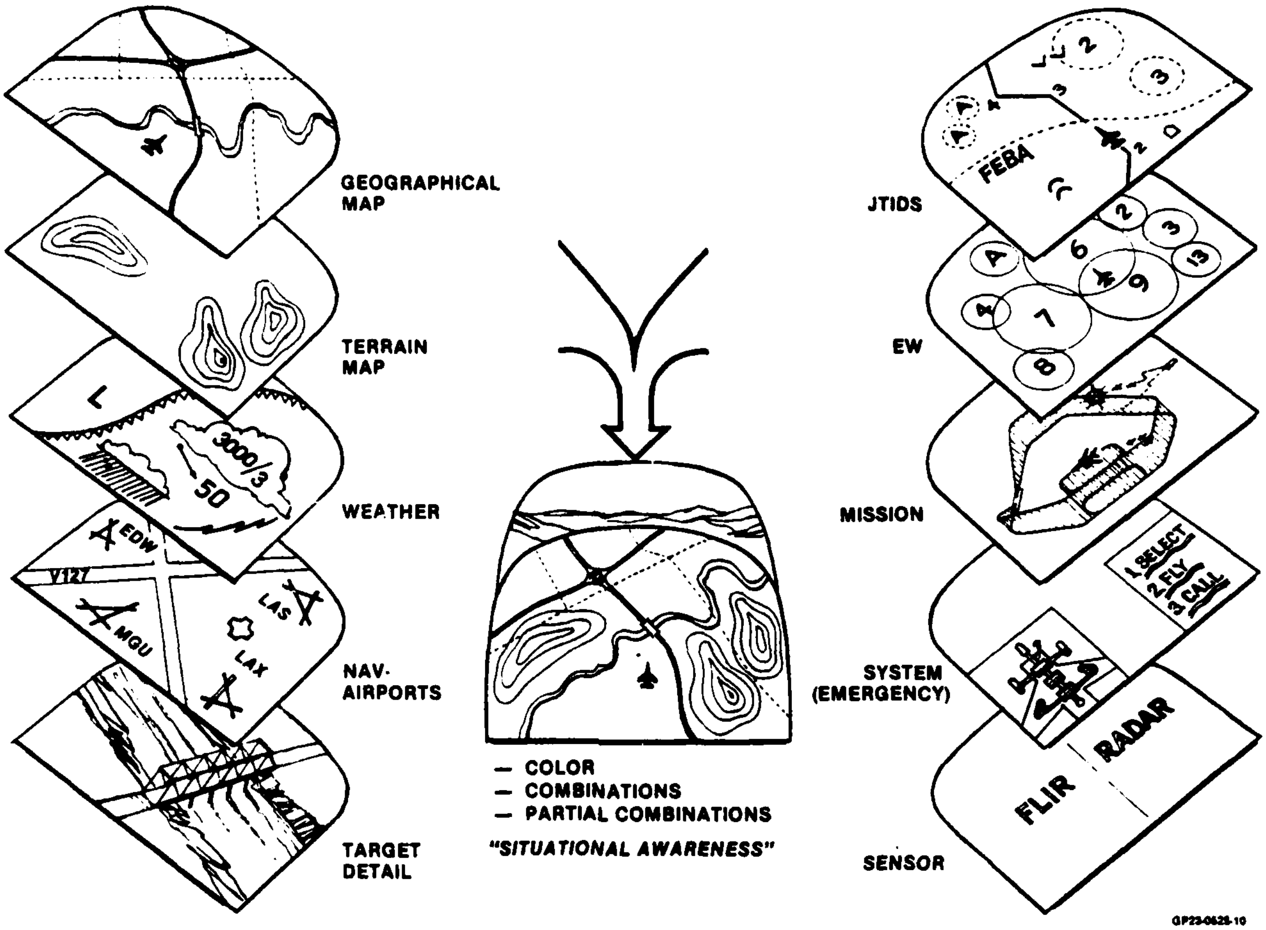

Figure 7. Example Data Plates

It was concluded that a combination of new and developing computer generated imaging, and bright high resolution display technologies offer a method to match the pilot's abilities and meet the needs of future fighter aircraft missions/ systems. Further, it was concluded that a laboratory facility, such as the Manned Air Combat Simulator (MACS), would provide a cost effective means for developing and testing these new concepts. The development plan recommends a test cockpit that can be included within a full mission simulator environment for the next phase. In that phase, the DTACS concepts can be developed and tested for effectiveness in advance of flight testing. The evaluation/performance measures and capabilities/limitations of proposed designs would be documented and fruitful approaches for further development identified.

The following key results of the study are summarized in this report:

1) Anticipated future fighter/attack missions and display requirements are reviewed and display designs are proposed.

2) New and developing technology is identified which can be innovatively applied to reduce pilot work load and provide unprecedented "situational awareness".

3) Requirements for a laboratory facility to simulate and test the proposed concepts are defined.

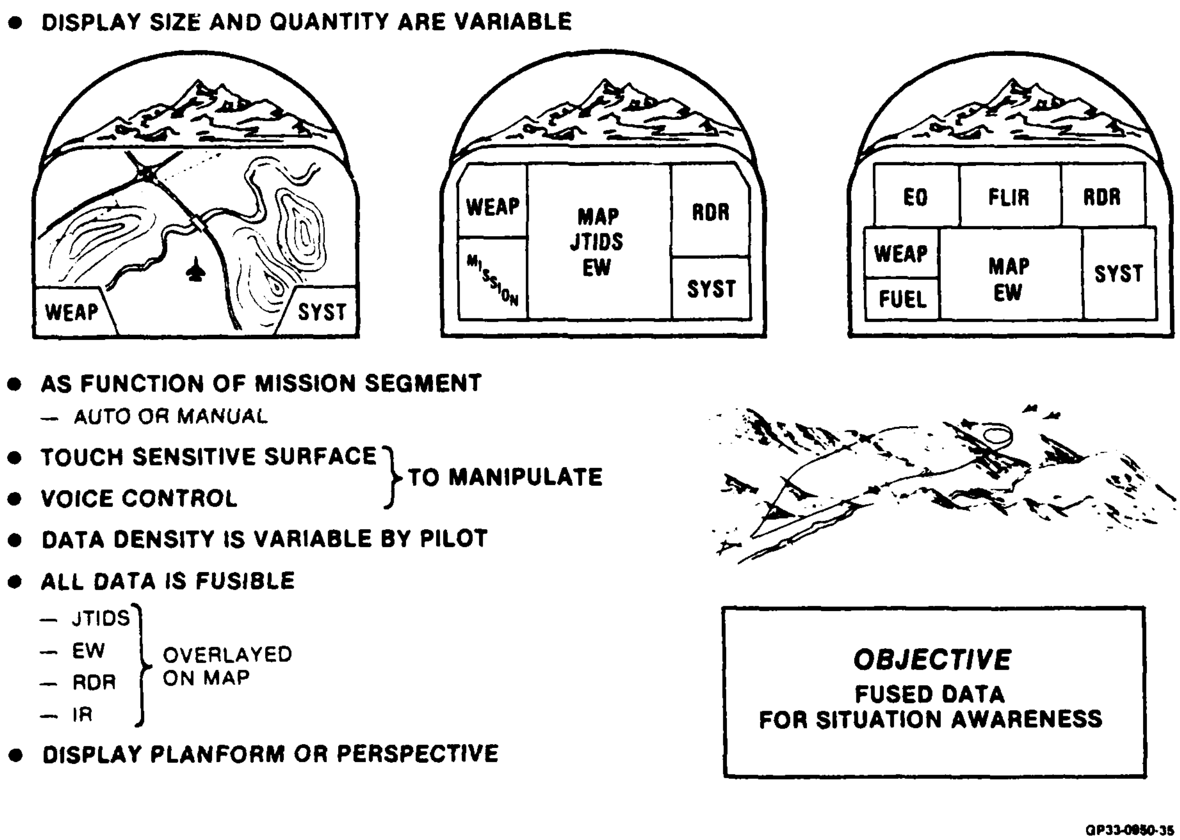

Figure 8. Required Instrument Panel With Example Format

2.0 AIRCRAFT/MISSION DESCRIPTION

A baseline aircraft, weapon system, and various missions were defined and then used to determine the assumptions and resulting requirements for the study.

2.1 BASELINE WEAPON SYSTEM

A baseline weapon system was defined to be consistent with the expected capabilities of advanced fighter/attack aircraft expected to be operational in the 1990's. This weapon system includes a multimode radar with air-to-air and air-to-ground capability, an Infrared Search and Track System (IRSTS), a Forward Looking Infrared (FLIR) system, an advanced flight control system, an advanced electronic warfare system, and a highly accurate navigation system.

Multimode Radar

The onboard multimode radar provides for both air-to-air and air-to-ground operation. The air-to-air modes include:

- o Range While Search
- o Velocity Search
- o Track While Scan
- o Air Combat Maneuvering
- o Single Target Track
- o Raid Assessment
- o Non Cooperat ˒ Target Recognition
- o Receive Only

These radar modes give the aircraft an all-weather, all aspect, long range look up and look down capability.

The air-to-ground radar modes include:

- o Real Beam Ground Map
- o Doppler Beam Sharpening
- o Synthetic Aperture Radar (SAR)
- o Ground Moving Target Detection and Indication (GMTI)
- o Map Freeze
- o Precision Velocity Update

- Air-to-Surface Ranging
- Precision Target Track of Fixed and Moving Targets
- Terrain Following (TF)
- Terrain Avoidance (TA)

The SAR mode produces radar ground maps of almost photographic quality. The SAR process provides high resolution maps by synthetically generating a very large antenna by having the aircraft's antenna look at a fixed point on the ground while the aircraft moves. The target return data is sampled and processed, creating an effective antenna size equal to the distance the aircraft travels during the sampling period. Figure 9 presents the SAR process. Since operation in this mode relies on doppler effect processing, the mode is not operable for targets along the aircraft ground track or so near to it that the frequency shift is too small for processing. This area extends approximately ±10° from the aircraft's ground track, as shown in Figure 10.

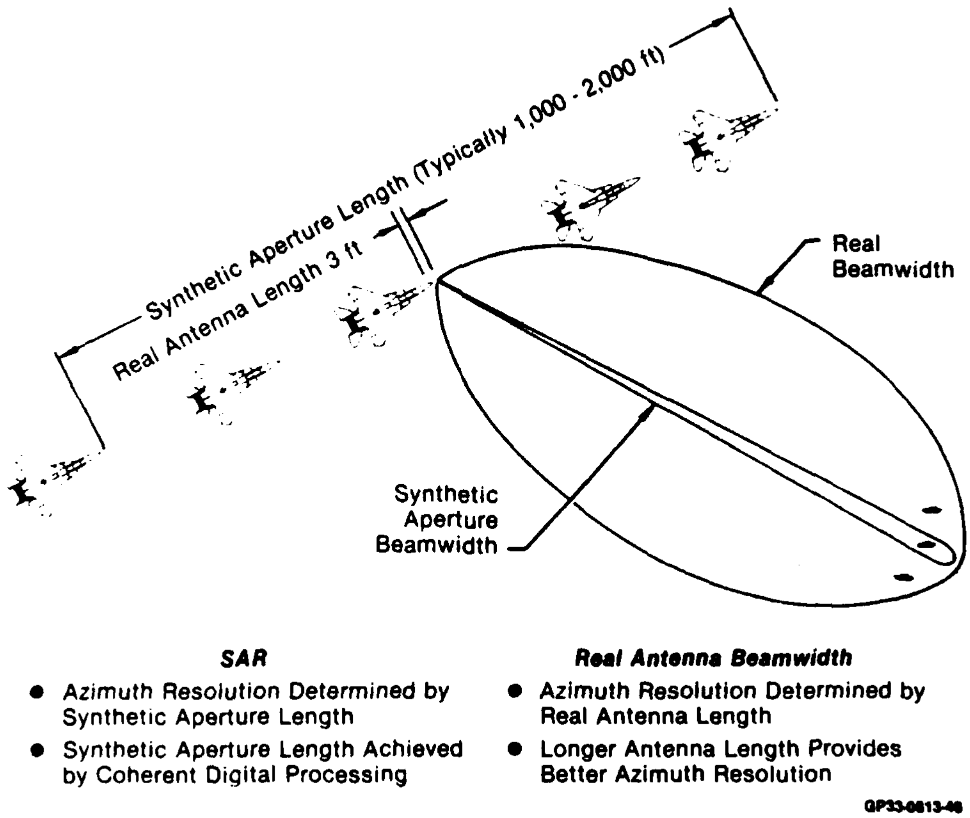

Figure 9. Synthetic Aperture Radar

Infrared Search and Track System (IRSTS)

The IRSTS provides range and azimuth information on air-to-air targets located in the aircraft's forward hemisphere. The IRSTS has modes similar to those of a radar (track while scan, raid assessment, single target track) and can be operated as a supplement to radar or as the primary sensor.

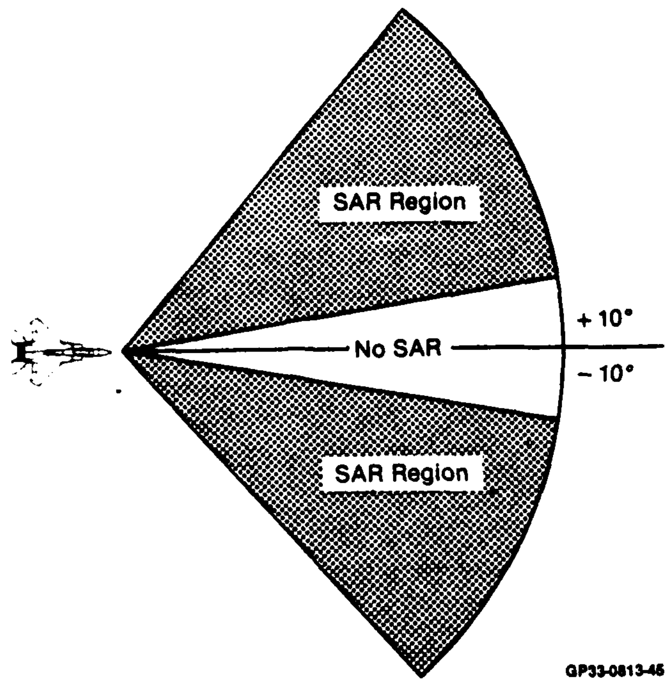

Figure 10. Ground Plan

Forward Looking Infrared Sensor (FLIR)

The FLIR used on the baseline aircraft is a pod mounted sensor with two fields of view, 12° x 12° wide field of view and 3° x 3° narrow field of view. It has a field of regard of +30°, −150° elevation and ±540° roll. The FLIR can be cued to a line of sight as designated by the radar or navigation system, and has an inertial tracking mode.

Advanced Flight Control System

The baseline aircraft is equipped with a flight control system which includes a full set of pilot relief modes (e.g. attitude hold, altitude hold, heading hold), is designed to implement automatic terrain following/terrain avoidance, and is coupled into the fire control system to provide improved accuracy during weapons use. The fire control system coupling is based on the results of studies such as Integrated Fire Flight Control, Integrated Flight Weapons Control, Integrated Flight Trajectory Control and the Maneuvering Attack System.

Advanced Electronic Warfare System

The advanced electronic warfare system includes both warning and active countermeasures. The warning portion of the system is designed to be operable in a high density threat environment, provides wide band receiver coverage, incorporates advanced processing architecture using high technology concepts (VHSIC - VLSI - SAW-GaAs), and provides integrated countermeasures management against IR, RF, EO and Laser guided threats. The active countermeasures include jammers with wide angle coverage, electronically steered beams and high effective radiated power.

Navigation System

The baseline navigation system includes a highly accurate onboard Inertial Navigation System (INS) and links to the Global Positioning System (GPS). This will provide a navigation system accuracy of $\pm$10m in position and 0.1 m/sec in velocity.

2.2 AIR-TO-AIR MISSION

The fundamental objective of the air-to-air fighter is to suppress enemy air operations in a theater. This permits, except for surface defenses (e.g., SAMs), friendly air operations (attack and reconnaissance) against enemy surface forces, and prohibits enemy air operations against friendly forces. That objective will be the same in 1990-1995 time-frame. However, technological advances may change the tactics necessary to attain these objectives. The following descriptions outline each of four different scenarios, fighter sweep, escort, intercept and combat air patrol missions.

2.2.1 Fighter Sweep - The objective of the fighter sweep is to gain air superiority by searching out and destroying airborne threat forces. The fighter sweep is a preplanned, offensive mission. It may be used to clear the intended flight path of a strike flight or to destroy airborne targets of opportunity over enemy territory. It is best employed as an independent operation in areas where no other friendly aircraft are operating. This eliminates the friend or foe identification problem and allows the flight to fire on any aircraft detected.

A fighter sweep mission is illustrated in Figures 11 and 12. Figure 11 illustrates a high altitude penetration and Figure 12 shows a low level penetration. The friendly flight will probably employ a clustered, "attack-like" formation. Among the reasons for using such a formationare:

1) attempt to confuse enemy radars as to number of aircraft and mission objective of the formation,
2) saturation of surface-to-air threat systems (SAM, AAA)
3) maintenance of easy visual contact among friendly aircraft,
4) maximum concentration of friendly forces in air combat maneuvering engagements.

The sequence of battle will probably consist of detection, BVR (beyond visual range) exchange, kill assessment (friendly and threat), and CIC (close in combat). If identification is not required, the friendly flight leader may assign BVR missiles quite liberally to any radar detected targets. The capabilities of TWS (Track While Scan) radar and AMRAAM (Advanced Medium Range Air-to-Air Missile) type missiles are important to a favorable BVR engagement. The friendly flight leader is probably free to decide to close on threat survivors for a maneuvering engagement or to return to base. Information on the results of the BVR exchange is needed as a basis for his decision.

2.2.2 Fighter Escort - The fighter escort mission is flown to provide protection for the primary mission aircraft from enemy air attack. Primary mission aircraft may be attack, bomber, transport, reconnaissance or other fighter aircraft. The escort mission is flown with visual and/or radar coverage over the primary mission aircraft. The primary mission usually considered is an attack (strike).

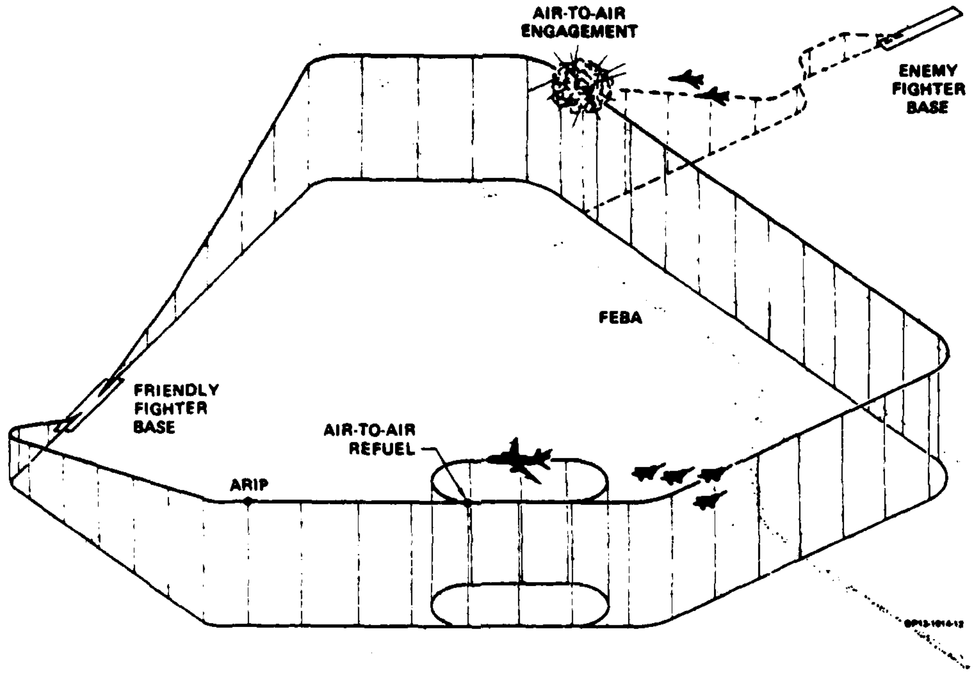

Figure 11. Fighter Sweep - High Altitude Penetration

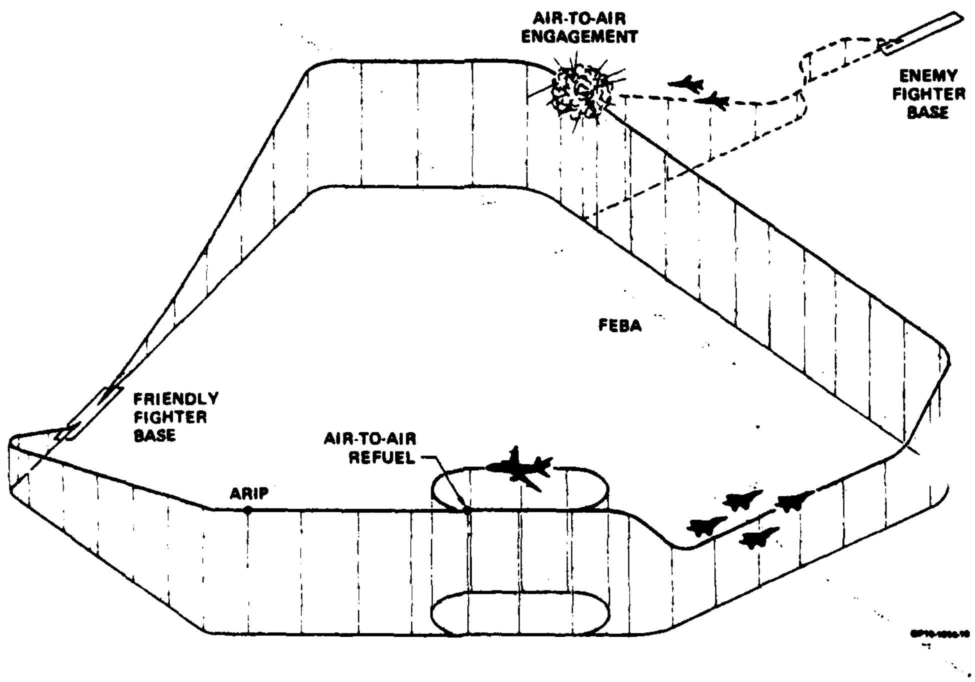

Figure 12. Fighter Sweep Low Altitude Penetration

The objective of the escort aircraft is to protect the strike aircraft against airborne threats. This may be accomplished by killing or engaging threat interceptors. The interceptors must be engaged until the strike aircraft have completed their mission. Only aircraft which pose a threat to the escorted aircraft would be engaged. If necessary, a BVR exchange would be initiated, however, a much more conservative allocation of missiles than the fighter sweep tactics would be employed. Some missiles must be retained until the strike aircraft have completed their mission. After kill assessment, appropriate maneuvering combat engagements would be initiated to occupy the remaining threat and thus allow the strike aircraft to complete their mission.

Figure 13 shows a composite strike mission illustrating the role of the escorts. Coordination of rendezvous between attack aircraft and fighter escorts is necessary to provide proper protection. The information flown must be properly coordinated to provide necessary coverage. In theory, fighter escort would bracket the aircraft being escorted. Such an escort formation requires visual station keeping which necessitates good in-flight visibility. In conditions of reduced visibility, the escorts drop back and fly a radar formation. Care must be taken when escorting a low, fast strike force utilizing terrain masking so as not to highlight the strike to surface or air threats.

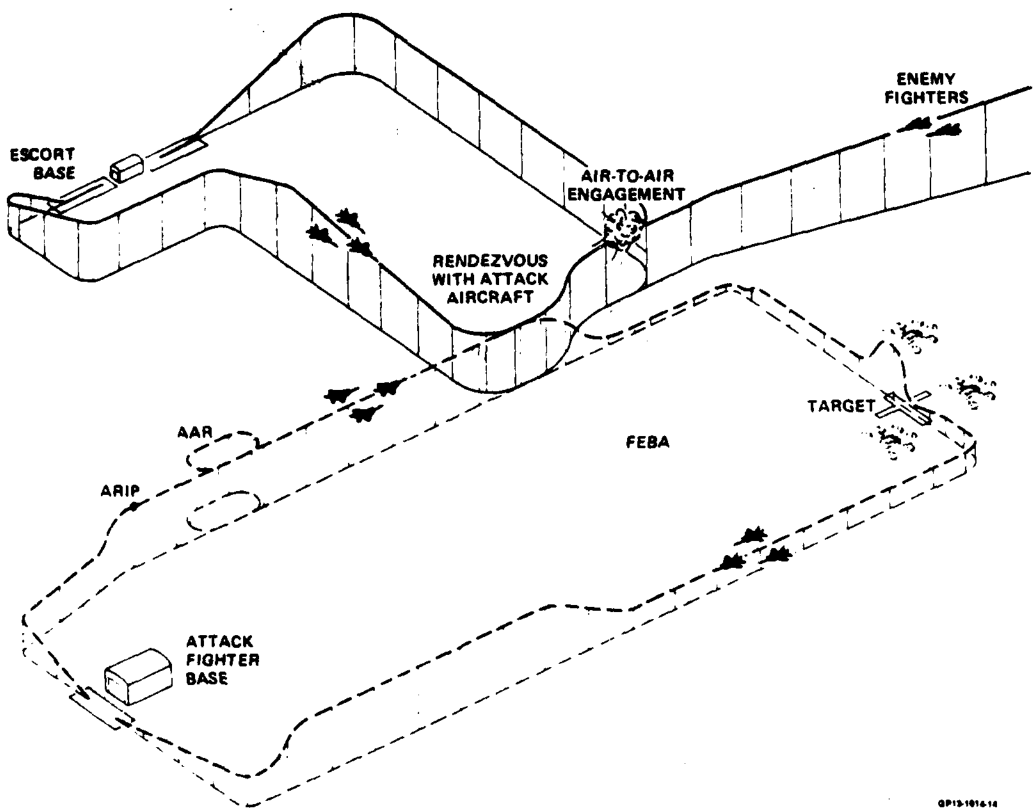

Figure 13. Escort Mission

2.2.3 Intercept - The objective of the intercept mission is to prevent penetrating enemy aircraft from completing their mission. This may be accomplished by destroying enemy fighters or bombers, or engaging enemy bombers so that they are unable to complete their mission.

It is assumed that the friendly aircraft are on ground alert. Penetrating enemy aircraft are detected by surface and airborne warning systems. The fighters are scrambled and contact a CCI (Ground Control Intercept) station or an AWACS (Airborne Early Warning and Control System) as soon as they are airborne. This communication provides the necessary information to vector the interceptors to the penetrating enemy aircraft. Figure 14 illustrates the intercept mission. The penetrating enemy aircraft may have been tracked inbound from enemy territory or may have already been engaged by friendly fighters. The altitude and location of friendly forces need to be considered in selection of firing doctrine. In the case of an unmolested penetrating force, BVR missiles would be fired with close-in maneuvering combat to follow. The presence of friendly forces necessitates specific target identification before missile launch.

2.2.4 Combat Air Patrol (CAP) - The objective of the CAP mission is to provide temporary air superiority over a given area to protect friendly air or ground forces from attack by air during the conduct of their operation. The airborne CAP station intercepts hostile aircraft and prevents them from reaching their target. CAP may also be used to provide a barrier between an enemy threat and friendly positions.

The CAP station may be authorized to launch BVR missiles on unidentified penetrating aircraft. However, friendly flights returning to base from their missions may complicate the situation. The penetrating threat must be engaged to prevent them from reaching their targets. Figure 15 illustrates fighters leaving their CAP station to engage a penetrating threat.

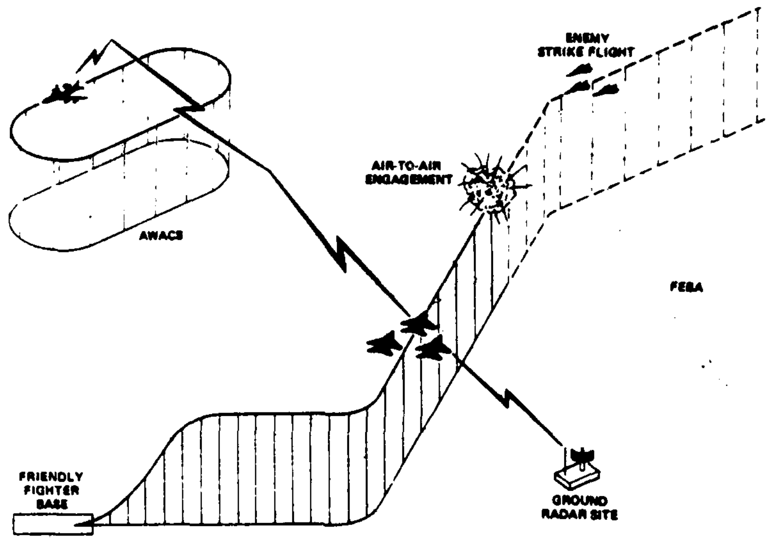

Figure 14. Intercept Mission

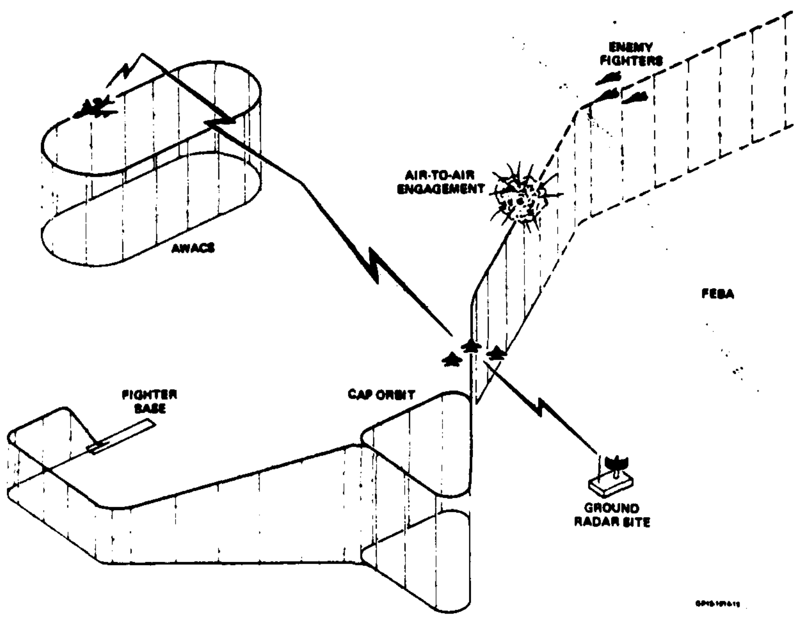

Figure 15. Combat Air Patrol (CAP) Mission

2.3 AIR-TO-GROUND MISSIONS

Two air-to-ground mission types were d^fined. They are 1) close air support (CAS) and 2) shallow battlefield interdiction (BI). Combinations of weapon type, target type, weather, threat, and day/night conditions were considered. The weather conditions were picked to be typical of those found in Central Europe, including reduced visibilities (3 miles or less), low cloud ceilings (3000 feet or less), rainfall, and snow.

The Central European area is considered a high density threat environment. The threat consists of surface-to-air missiles (SAMs), antiaircraft artillery (AAA), and air threats. The mission profiles were chosen with consideration of the threat environment.

Three representative mission scenarios were developed for this study. They are 1) CAS using IIR Maverick weapons, 2) BI using IIR Maverick, and 3) BI using MK-20 Rockeye.

2.3.1 Close Air Support (CAS) - The CAS mission is a short range mission flown to help ground forces obtain and maintain the offensive or to blun an enemy attack. We assumed the target would be a tank column on a road, approximately 5 NM from the FEBA. The mission profile is illustrated in Figure 16. The aircraft takes off and climbs to 10,000 feet. A SAR map is made during the descent to the target area (approximately 5,500 feet altitude, 20 NM target range, 2.5 degree antenna depression angle). The aircraft descends to 200 feet above ground level (AGL) and uses manual terrain following. Twenty seconds are required to screen the SAR map during this flight segment. A popup is initiated at 6.5 NM from the target. At the FEBA, target designation is made using the FLIR. A 5 degree dive to the target for weapon delivery. Five seconds are required for acquisition, designation and release of the IIR Maverick. Weapon release is at 2.3 NM from the target. Egress is at 200 feet AGL until well clear of the battle area.

2.3.2 Battlefield Interdiction (BI) - The purpose of the BI (Battlefield Interdiction) mission is to destroy, neutralize, confuse or delay enemy ground forces. We assume a shallow BI mission. The target is located 40 NM inside the FEBA. Two types of targets and weapons are assumed. The first is a tank column on a road between tree lines approximately 40 NM from the FEBA. The tank column is attacked using the IIR Maverick. The second target type is a fixed TOC (Tactical Operations Center) located in a wooded area also 40 NW inside the FEBA. The TOC site consists of six vans and the supporting vehicles. The TOC is attacked with 12 MK-20 Rockeyes.

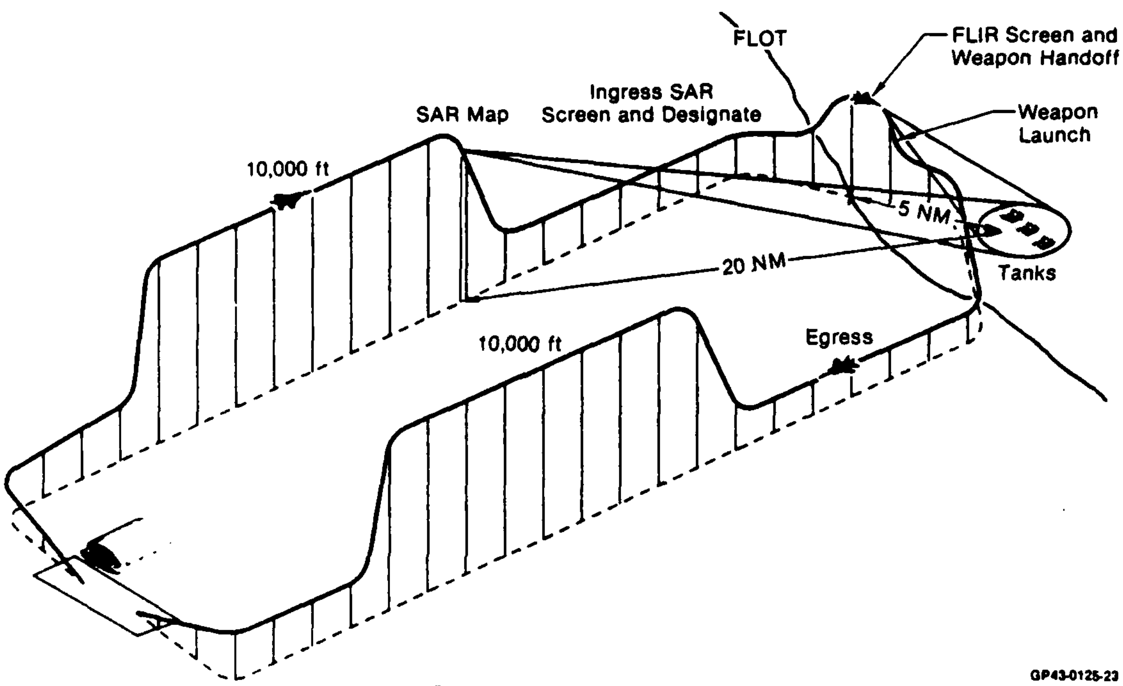

Figure 16. Close Air Support (CAS) Mission

The profile of the advanced baseline attacking the TOC with Rockeyes is shown in Figure 17. The aircraft takes off and climbs to 20,000 feet for cruise. The aircraft descends and is at 200 feet within 5 NM of the FEBA. At approximately 20 NM from the target, the aircraft pops to the altitude needed to unmask the target. Five seconds at pop altitude is required to make a SAR map. The aircraft returns to low level and continues the ingress. Penetration is at 200 feet at Mach 0.8. The SAR map is screened while flying low level and the target designated. Twenty seconds is allotted for this process. A pop-up for a 5 second SAR update is made 6.5 to 5 NM from the target and final target designation is made. We assume a 4 g toss weapon delivery. A 15° toss at 1.8 NM and 1000 ft is used. The egress is made at 200 feet at Mach 0.8 using the TF mode.

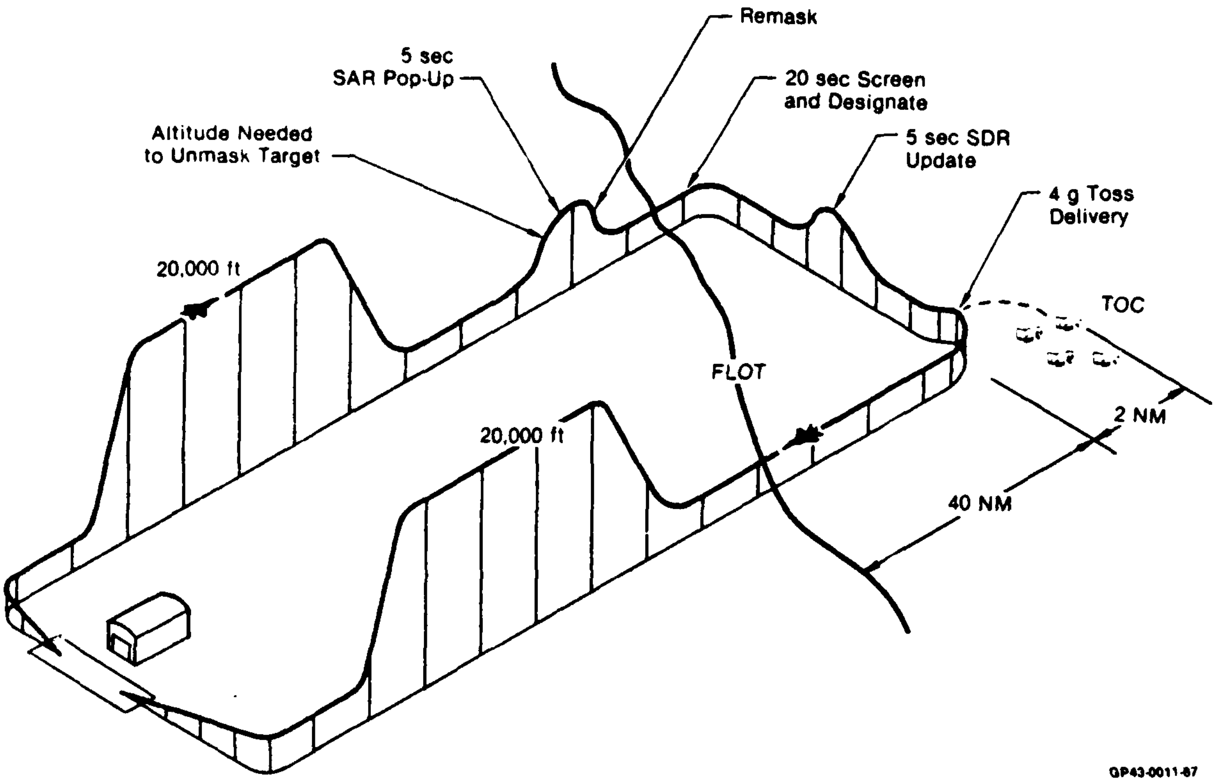

Figure 17. Battlefield Interdiction (BI) Mission - MK-20 Rockeye

The BI mission attacking a tank column with IIR Maverick is shown in Figure 18. We assume the profile is the same as the previous BI mission profile through the ingress and penetration phase. A SAR map is made 20 NM from the target at an altitude required to unmask the target. Five seconds at pop-up altitude is required to make the SAR map. The aircraft remasks and the map is screened and the target designated. We assume this can be accomplished in 20 seconds. At approximately 4.4 NM from the target a climb to 1000 feet (ceiling limited) is initiated. Starting at 1000 feet altitude, target acquisition, designation and weapon launch are accomplished in a 5 degree dive. The weapon is released 2.3 NM from the target. The aircraft egresses at 200 Mach 0.8.

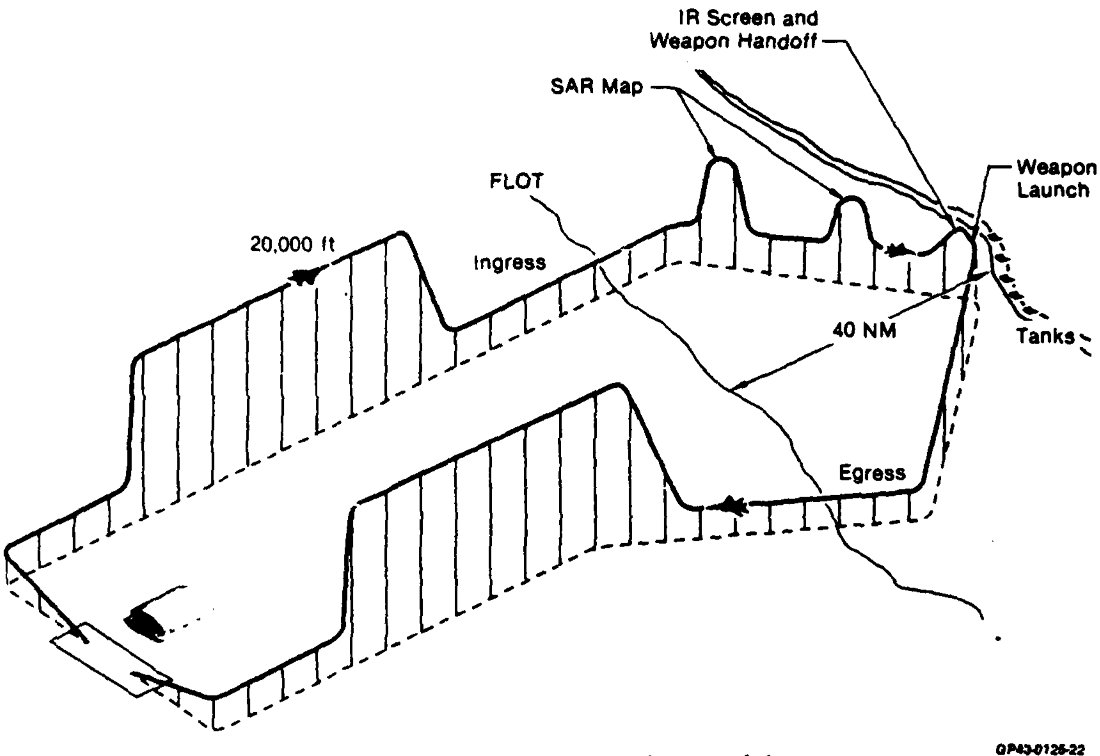

Figure 18. BI Mission - IIR Maverick

3.0 CREW INTERFACE FEATURES

This section deals with the requirements necessary to provide a cockpit display system which will provide unprecedented situational awareness to the pilot. Various display technologies are evaluated for use in a cockpit display and for use in a flight simulator for concept demonstration. Typical display formats for use in the cockpit are discussed. Cockpit control techniques are reviewed for their application to the large format display concept. A preliminary design for an aircraft display configuration was made, and risk, maintainability, reliability, availability, and life cycle costs are discussed for this configuration.

3.1 DISPLAY TECHNOLOGY REVIEW

Part of the DTACS study effort has been directed to evaluating those advanced display technologies which show promise for solving the lack of situational awareness in present cockpits. Figure 19 shows a general classification of the electronic information displays investigated.

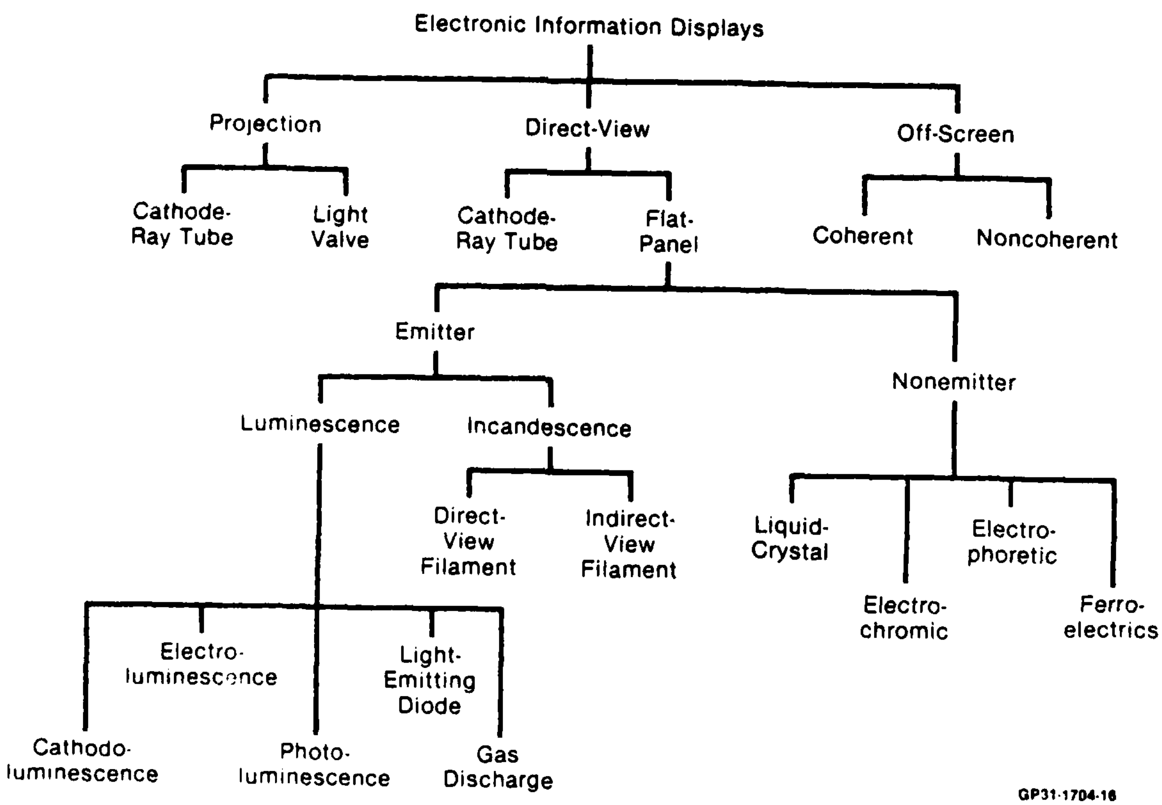

Figure 19. Classification of Electronic Information Displays

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Three major roots exist in the technology classification tree shown in the figure; projection, direct-view, and off-screen. Each implies the means by which the respective displays are presented to the observer. Projection implys an optical system, refractive or reflective, which presents a real aerial image, focused on a viewable screen. Direct view is just that. It implies a direct observation of the points in space where the display image is generated. An example of this is directly viewing a Cathode Ray Tube (CRT) display. Off-screen is meant to include virtual images produced by refractive, reflective or holographic means. A Head Up Display (HUD) is an example of an off-screen electronic presentation device.

3.1.1 CRTs - The ubiquitous cathode ray tube appears in all branches of electronic information display technology. This includes projection, direct view and off-screen HUD presentations emphasizing holographic optics.

Commercial television has contributed greatly to the development of color and monochrome CRTs. So many advancements have been made that the CRT has become the dominant electronic information display device and it's still improving. Miniature CRTs are being developed with monocrystalline luminescent screens that will achieve luminances of several orders of magnitude more than can be obtained with conventional phosphor screens (Reference 1).

3.1.2 Light Valves - Light valve technology is well developed by General Electric in the oil film approach. 1000 line 1000 lumen projectors are in common use throughout the simulator industry. However, the full color oil film projectors are limited to raster displays due to their Schlieren optical systems. Extensive work on raster correction has shown that no more than about 5% deviation from a rectangular raster sweep can be tolerated in such a system without unacceptable color distortion. The oil film approach is therefore not applicable to calligraphic (beam drawn) displays. Other light valves are under development, however, that can draw calligraphic images. These include potassium diphosphate (KH_2PO_4 or "KDP") crystals (Reference 2) and various approaches using liquid crystals (LC) as light valve modulators. SODERN of France has the TITUS tube KDP technology and Hughes Aircraft Company (Reference 3) has under development both light and MOS addressed high resolution (1000 line) liquid crystal (LC) light valves. Tectronix (Reference 4) is investigating and has laboratory models for electron beam addressed liquid crystal light valve devices. MCAIR has recently patented an E Beam addressed LC light valve (U.S. Patent 4,387,964).

3.1.3 Off Screen Displays - Off-screen devices provide a virtual image that can be focused from very close to infinite distances. The observer views this image as if it were originating from the controlled focus distance. In an aircraft the head-up display is focused at infinity to superimpose the pilot's normal view out the windscreen with the electronically displayed information. For simulation visual systems, with the observer at the dome center, the HUD image is focused at the dome radius (approximately 20 feet).

Off-screen displays can incorporate coherent or non-coherent image sources. A projected laser image (coherent source) can be holographically formed. Non-coherent sources, both emitters and non-emitters, e.g. CRTs and Liquid Crystal Displays (LCD), can be used to form virtual images by means of reflective or refractive optical systems. Holographic lenses are also applicable to providing virtual images from CRTs if the color of the CRT light output is properly matched at the monochromatic wave length designed for the holographic lens. Most wide angle HUDs use this principle.

3.1.4 Flat Panel Displays - Flat panel technologies are classified as either emitters (light sources) or non-emitters (passive display devices). Flat panel technologies are improving and are expected to compete with CRTs in future applications. Figure 20 lists the flat panel display technologies and delineates the physical phenomena associated with each.

Emitting Displays

Emitting displays are limited in their light output by their respective luminous efficiencies. The luminous efficiency (LE), in lumens per watt, is a highly useful parameter in evaluating a display device. It provides a qualitative measure of the device practicality and a quantitative measure of its performance. A low luminous efficiency infers high power or lower brightness. Increased power is associated with higher temperature, shorter life and bulky/costly electronics. Figure 21 shows the luminous efficiencies for the various emitting display types.

Emitting Displays	
Gas Discharge	Cathode Glow From Conducting Gaseous Discharge
Plasma Panel	AC Capacitively Coupled Gas Discharge
Light-Emitting Diode	Electron Injection in a Forward-Biased p-n Semiconductor Junction
Vacuum Fluorescence	Electron Bombardment of Phosphor in Hard Vacuum Under Control of a Grid or Cathode
Electroluminescence	Filamentary Condition in Polycrystalline Phosphors Due to High Electric Field
Flat Cathode-Ray Tube	Electron Bombardment of Phosphor in Hard Vacuum Under Control of a Grid or Cathode

Nonemitting Displays	
Liquid Crystal	Electrostatic Rotation of Organic Compounds Which Exhibit Nematic Liquid Crystallinity
Electrochromic	Charging and Discharging Chemical Systems Which Exhibit a Color Change in Accordance With Faraday's Law
Electrophoretic	Electrostatic Transport of Color-Absorbing Particles in a Colloidal Suspension
Suspensions	Electrostatic Rotation of Light-Absorbing Needle-Shaped Particles in a Colloidal Suspension
Magnetic Particles	Magnetic Rotation of Light-Absorbing Particles
Ferroelectrics	Electrooptical Effect in Ferroeiectric Polycrystalline Material

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Figure 20. Flat Panel Technologies

Clearly, Figure 21 depicts the advantage of the CRT over the other display types in terms of luminous efficiency. However, despite this advantage, research continues in the LED, PDP and EL technologies. An AC PDP has achieved a reproduction of a (480) line commercial video picture with "reasonably good gray scale". An EL panel was recently evaluated that employed a matrix of 320 columns and 240 rows in a 6 inch diagonal, 0.5 in. thick panel. The unit was assessed with TV and in-raster graphics video formats of the "Big Picture" or DTACS type. Six EIA logarithmic shades of gray were evident in normal room lighting. Alphanumerics 0.12 inch high were readable. However, brightness, the small screen size, and lack of color negates its use in the DTACS concept. LED technology was similarly negated for DTACS use because of its low luminous efficiency and high cost.

Display Type	Best LE in Commercially Available Panel (lumens/watt)	Experimental Range
LED	0.06 Red and Green	10 — 4 Blue
AC PDP	0.3	0.2 to 1.0
AC PDP With Phosphor	—	1.0 Green
DC PDP	0.1	
DC PDP With Phosphor	—	3.8 Green, 0.8 Red, 0.4 Blue
DC EL Powder	0.5 to 1	0.5 to 3
AC EL Powder	0.5 to 3	1 to 5
AC EL Thin Film	0.2 to 1	0.5 to 2
Monochrome CRT	40 (Phosphor Only)	To 100
Color CRT (White)	8 (Phosphor Only)	

Legend:
Light Emitting Diode - LED
Plasma Display Panel - PDP
Electroluminescent - EL

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Figure 21. Flap Panel Display Luminous Efficiencies (LE)

Non-Emitting Displays

Non-Emitting Display devices have distinct advantages over the emitting types. They are immune to high ambient illumination and require a minimum excitation power by comparison.

Presently, LCDs dominate the low power, small display applications. The other technologies, electrochromism, electrophoresis and ferroelectrics, are in the research and development phase. These technologies show some promise in terms of improved contrast and resolution, however, there are no practical devices available and none anticipated in the near future.

Liquid crystal displays using the twisted nematic electro-optic effect are well known in many consumer electronic devices. The LCD displays range from watches, calculators, electronic instruments and computer displays, to small screen television receivers. Resolution is usually limited by the physical size of the character or pixel transparent conductive electrode.

Large screen displays in color are currently impractical, but a great many efforts are being made on dye-type LCD and miniscule (50 micrometer) RGB color filters within the glass sandwich of a twisted nematic display. The dye type LCD display is fundamentally limited in multiplex ability. A full-color matrix liquid crystal display, however, with color layers on the electrodes was recently developed in Japan. G.E. is developing similar technology. An experimental 56 x 56 RGB color matrix was produced using a photolithographic technique. Adjacent colors were visually mixed when observed greater than 20 inches away from the LCD. Although this technology is not as yet practical for immediate application to the DTACS simulation, it shows promise for future use.

Recommended DTACS Displays

Of all the display technologies reviewed, the CRT, used either in projection or direct view, shows the greatest promise for the DTACS simulation configuration. CRTs are currently used in airborne off-screen display devices. The head-up display and calligraphic presentations on a moving map are examples of off-screen electronic information displays that use CRTs. The DTACS size requirement with moving map, SAR, EO/IR, calligraphic, and color raster data has been reviewed and rear screen projection selected as the means for a multi-media display simulation. To demonstrate the concept a 15" X 20" display is thought to be adequate, although other sizes might be flight tested or placed into operational use. This approach can be easily augmented to apply light valve technology to the simulation when it is available. The initial design, however, should incorporate red, green and blue projection CRTs, a film strip moving map projector, and 2 black and white CRT projected display images. The R, G, B tubes can be used in either calligraphic or raster mode selectable under computer control. Variable line scan rates should be selectable for the RGB display in raster mode. Either 525 line or 1000 line, 30 hz, interlace or non-interlace raster displays need to be accommodated. The EO/IR and SAR data can be presented on the black and white projected CRT displays at 525 lines interlaced 2:1.

The DTACS simulation configuration can use both refractive and reflective optics to produce a virtual image HUD. A large spherical mirror and beam splitter can be combined to produce a wide angle (30°h x 20°v) field of view with the image distance adjusted to appear to originate at the dome surface. A conventional 6 in. diameter, high brightness monochrome (green) CRT and a high resolution projection lens can be used to provide the real image for the rear projection screen.

This optical combination, discussed in Section 4.6, is recommended for the DTACS simulation because of the flexibility of the off-screen technique. Image size, color format, resolution, relative brightness, and contrast can be conveniently simulated and varied to optimize the experimental HUD display.

The non-emitting display devices were rejected for DTACS simulation because of their inability to provide a large (15" x 20") color display. The selected projected CRT RGB color system provides the color capability and screen size desired. In addition, the CRT spot size is 4 mils in diameter, allowing 1000 TV lines in a 4" linear distance across the face of the CRT. At the magnification of 5 this will provide 1000 lines across 20 inches of the rear projected display or 50 lines per inch. At lesser magnifications higher line densities can be simulated.

The demonstration approach need only be sufficient to allow evaluating the DTACS concepts in a simulation environment. Higher brightness displays will be required for the flight hardware. The most promising technology for use in the flight hardware has been determined to be a pixel addressed LC light valve using dynamic scattering with zeroth order Schlieren optical projection. A 500 x 500 pixel panel can be mosaicked into a 15" x 15" array using a 3 x 3 matrix of the smaller panels. The display would represent 1500 lines over a 15 inch display or 100 lines per inch. Three to four thousand foot lamberts have already been achieved with this technique in a 5 x 7 inch fiber optic display panel. The major characteristics/problems anticipated in this technique are described in Section 3.4 of this report.

3.2 FORMAT REQUIREMENTS

DTACS display formats were developed for the takeoff, low level penetration, target acquisition with coordinated multiship attack, egress, beyond visual range air-to-air combat, approach and landing, and post mission.

3.2.1 Takeoff Format - The Head Up Display/Head Down Display (HUD/HDD) takeoff format provides all information required for a visual or instrument takeoff and departure, as shown in Figure 22. Aircraft attitude, airspeed, altitude, and heading are displayed on the HUD. The gear down velocity vector symbol is shown overlaid on the runway alignment arrow. Altitude is displayed in 10 ft increments to provide the accuracy required for instrument flight.

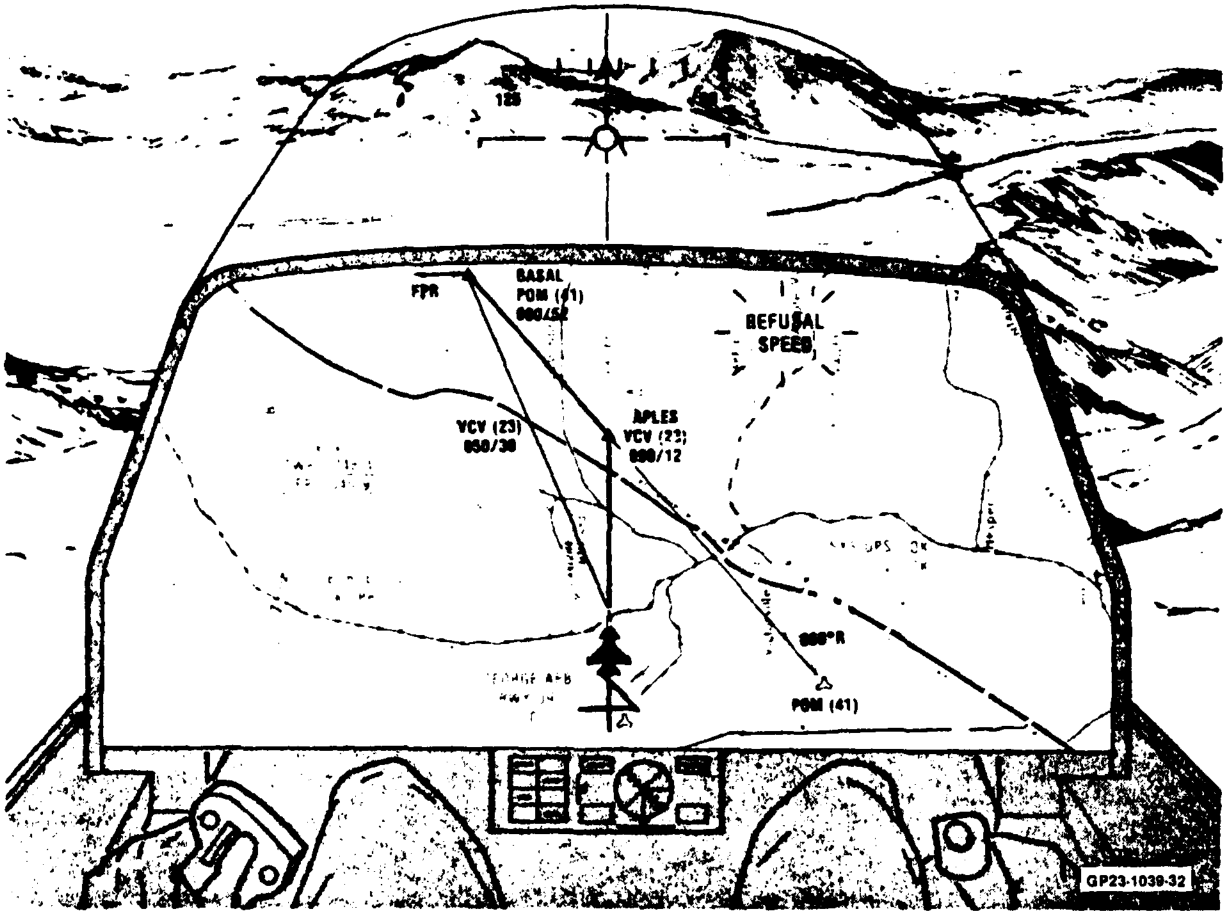


Figure 22. Takeoff Format

The HDD uses color symbology overlaid on a planar terrain map to provide readily discernable information.

A special cue, "REFUSAL SPEED", is provided below the HUD to notify the pilot that the aircraft is at the maximum unarrested abort speed for the specific gross weight and runway length. This information reduces pilot reaction time and increases the probability of the pilot making the correct decision in a high speed abort situation.

The aircraft position is displayed in a planar view relative to the appropriate SID (standard instrument departure). The enroute clearance is displayed in the lower left of the display. The three letter identifier of the tuned TACAN station and the required radio frequencies are displayed at the center left. The tuned radio frequency is highlighted. Systems status is shown for ownship and the wingman on the right side of the HDD.

3.2.2 Penetration Format - The integrated HUD/HDD format for a coupled TF/TA penetration or ingress is shown in Figure 23. The HDD terrain and surface-to-air

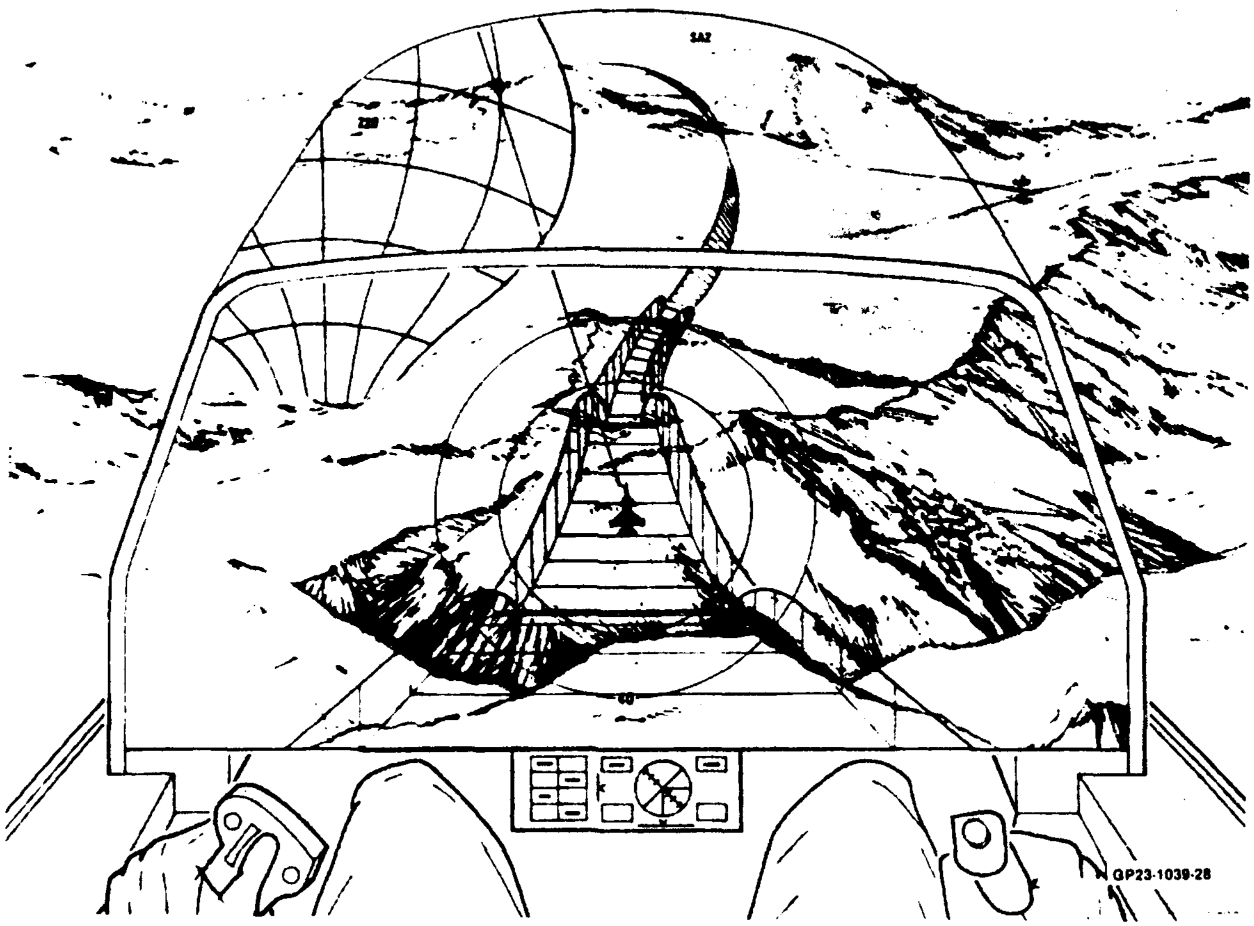


Figure 23. Penetration Format

threat envelopes are shown in perspective view, as indicated on the left side of the HDD. The surface-to-air threat displays depict threat capability and terrain masking effects and use color to indicate threat level. The forecast flight path for the selected 100 foot coupled TF clearance plane is displayed on the HDD in the form of a pathway.

The EW display and course line to the next waypoint (W3) are shown in planar view (PLANAR-EW). The heading and distance to the next waypoint and to the target are also displayed on the upper right portion of the HDD.

The displays for the coupled TF flight path, surface-to-air threats, and great circle path to the next waypoint are continued from the HDD into the HUD. The TF coupled cue and the selected clearance plane are also displayed on the HUD.

3.2.3 Target Acquisition with Coordinated Attack Format - This HUD/HDD format, Figure 24, provides the required information for the target acquisition phase. The HUD shows airspeed, radar altitude and barometric altitude and command flight path.

The HDD format presents a planar view of the terrain around the aircraft showing friendly, unknown and hostile aircraft, surface to air threats and the area of threat line of sight view at the aircraft's altitude. The inset in the lower right corner shows the target and initial point (IP). The three aircraft symbolic forms behind and right of the aircraft are the other members of the flight. The DTACS aircraft will be coordinating the attack on the target by the entire flight.

3.2.4 Egress Format - The egress format, Figure 25, shows many different data presented simultaneously on the HDD, while the HUD presents a computer generated out the window display with overlaid flight symbology. The out the window display is produced using the onboard digital landmass data.

The HDD presents range/fuel information, a digital plan view terrain map, threat display, onboard systems status (fuel), mission profiles and armament control.

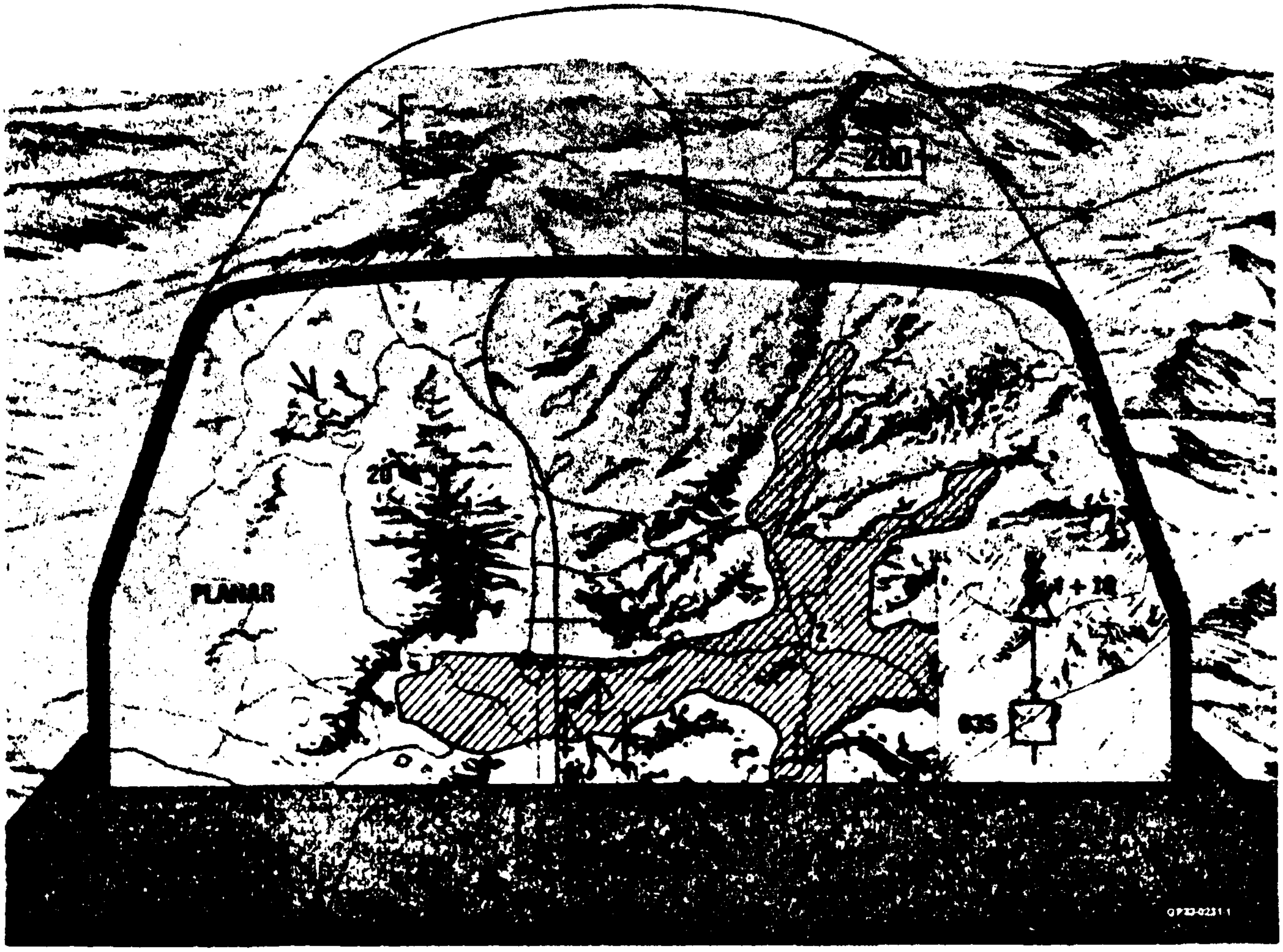


Figure 24. Target Acquisition and Co[illegible]d Multiship Attack

3.2.5 Air-to-Air Combat Format - The beyond visual range (BVR) air-to-air combat format, Figure 26, shows the HUD/HDD presentations of the data necessary to attack the BVR air-to-air target(s).

The HUD shows target attack information concerning the priority target (range, aspect angle closing velocity, altitude, etc.), surface to air threat information, and ownship flight parameters (heading, airspeed, altitude, attitude, etc.)

The HDD presents various inset subdisplays. A range/fuel display, an armament

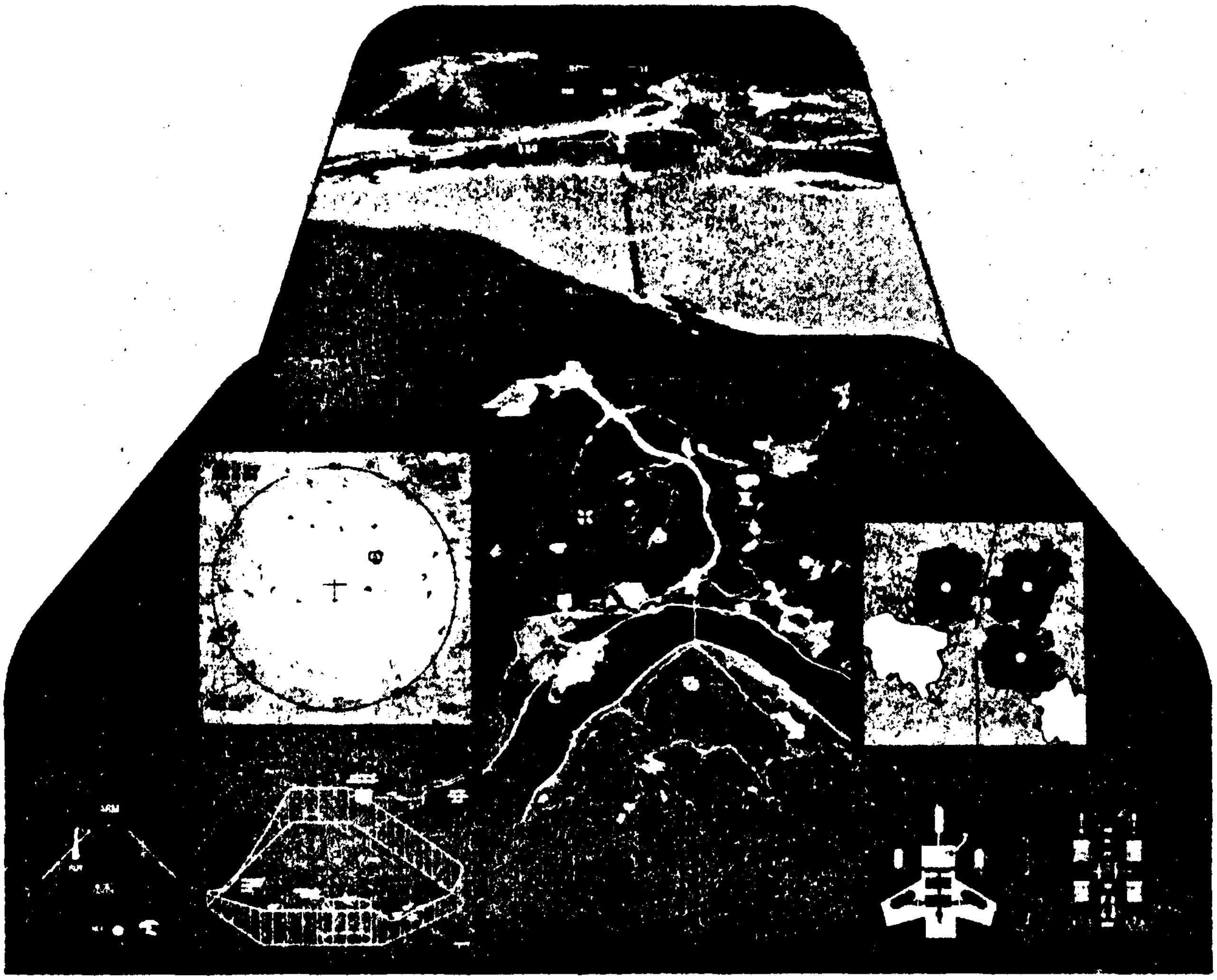


Figure 25. Egress Format

display, a sensor display, a threat display and several aircraft status displays are shown, as well as a planar map of the area around the aircraft.

3.2.6 Approach Format - The HUD/HDD approach format, Figure 27, provides all information required for a visual or instrument approach, i.e. to intercept the final approach course. Aircraft attitude, airspeed, altitude and heading are displayed on the HUD as well as an intercept flight path display.

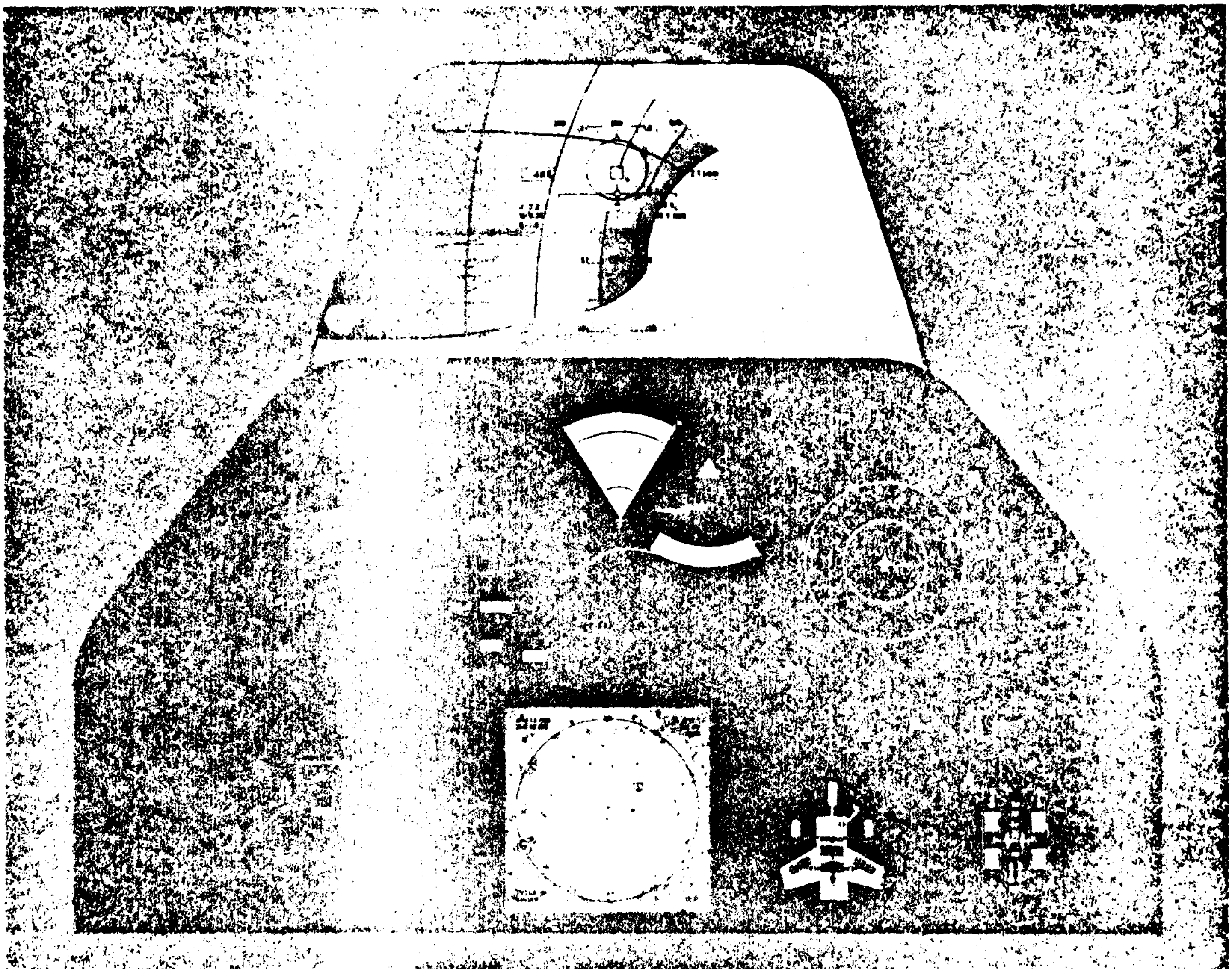


Figure 26. Air-to-Air Format

The "tadpole" flight director symbol is shown centered on the gear down velocity vector symbol. An angle of attack (AOA) bracket is referenced to the velocity vector. The center of the bracket represents the optimum approach AOA. The inverted T symbol below the velocity vector represents height above terrain. The TACAN station identifier and DME are also displayed on the HUD.

A planar view of the airfield, the ILS final approach course, and the forecast intercept path is displayed on the HDD. Mandatory altitudes are shown as well as other aircraft in the area.

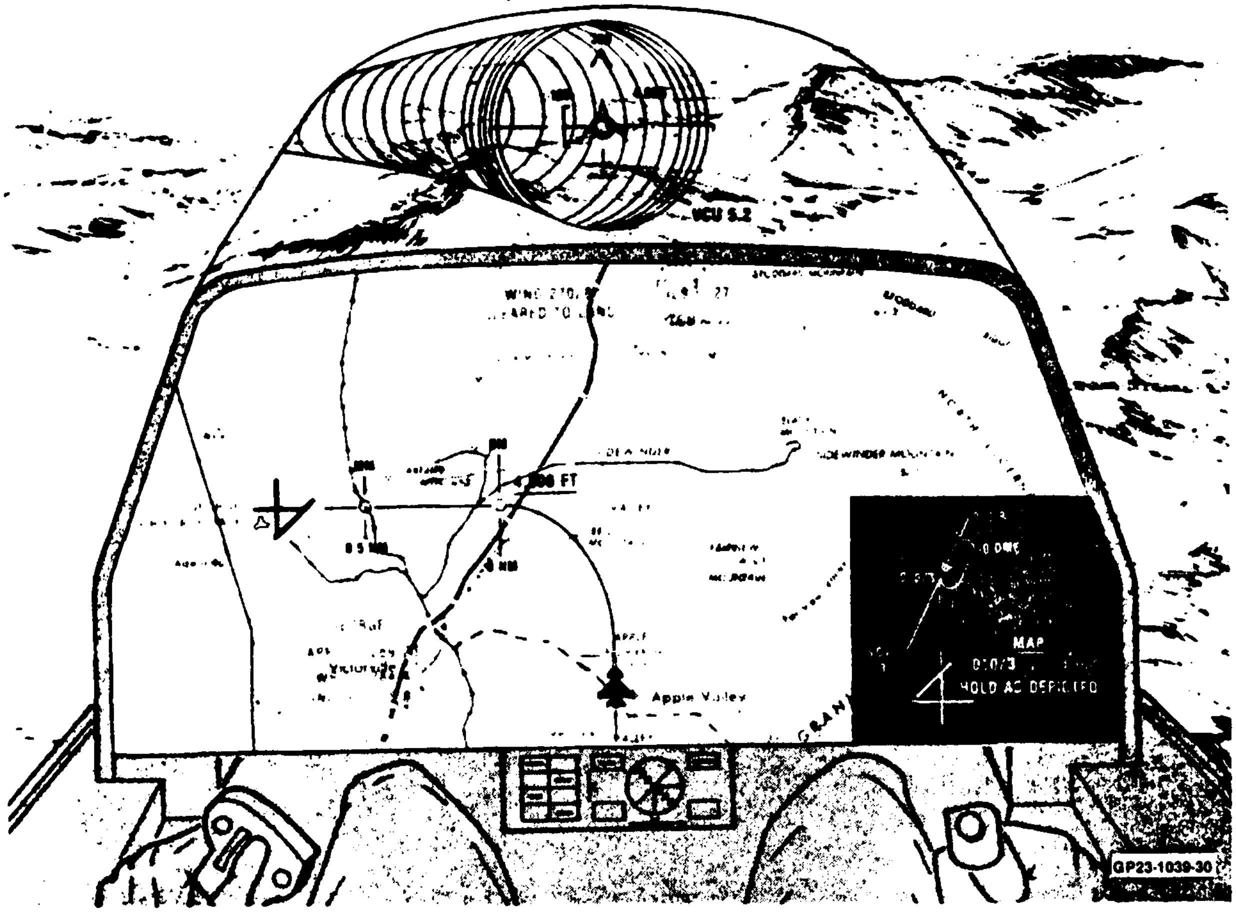


Figure 27. Big Picture Approach Format

The weather conditions and approach clearance are shown at the top of the HDD. The standard radio frequencies are shown and the tuned frequency is highlighted. Missed approach procedures are shown in the color raster display on the right.

3.2.7 Post Mission Format - The post mission format, Figure 28, can present any data required to help the ground crew properly survive and maintain the aircraft. This data, shown head down, would address areas such as required maintenance, failure analysis and systems status.

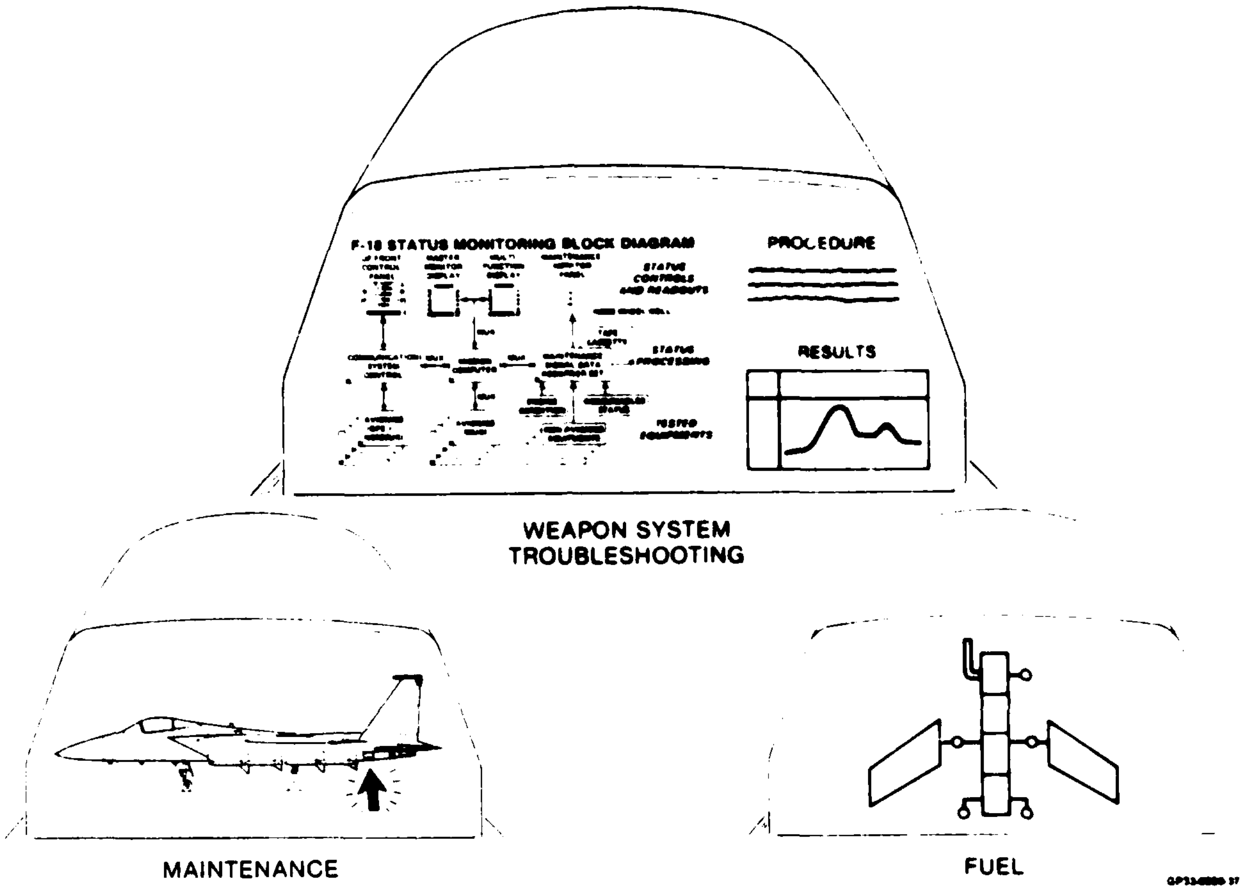


Figure 28. Post Mission

3.3 CONTROL TECHNIQUES REVIEW

The control technology to be used with the DTACS display was an area of study for this program. The large display area and the fusion of information from multiple sources requires a control method at least as sophisticated as the display concept. Various technologies were examined for their application to DTACS. They were:

- o Hands On Throttle And Stick (HOTAS)
- o Speech (or voice) Recognition Control (SRC)
- o Touch Sensitive Display Surfaces
- o Helmet Mounted Display/Sight (HMD/S)

3.3.1 HOTAS - The HOTAS control approach provides for pilot control of various subsystems without requiring him to remove his hands from either the flight control stick or the throttles. The pilot is able to perform the various control operations by using either dedicated switches or controls on the stick and throttles, or by controlling a cursor on a display to select options present on that particular display.

In the DTACS cockpit, the HOTAS control method would use some dedicated stick or throttle mounted switches to control functions requiring immediate action (weapon release, autopilot disengage, ECM etc.) and a display cursor (controlled from the throttle mounted cursor controller) to select options presented on the large format display. Figures 29 and 30 presents a typical stick and throttle designed for HOTAS use.

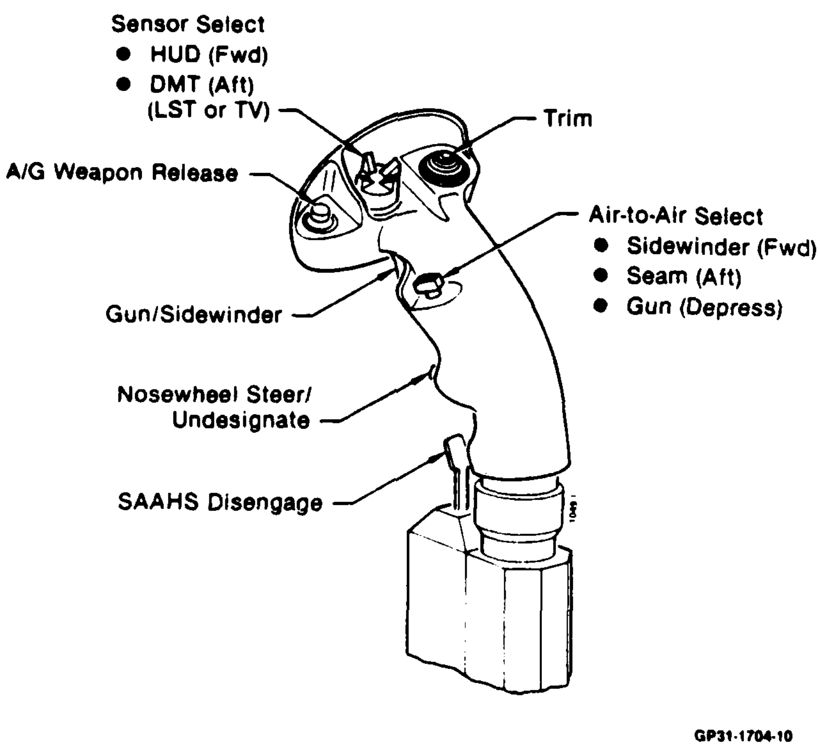


Figure 29. Flight Control Stick

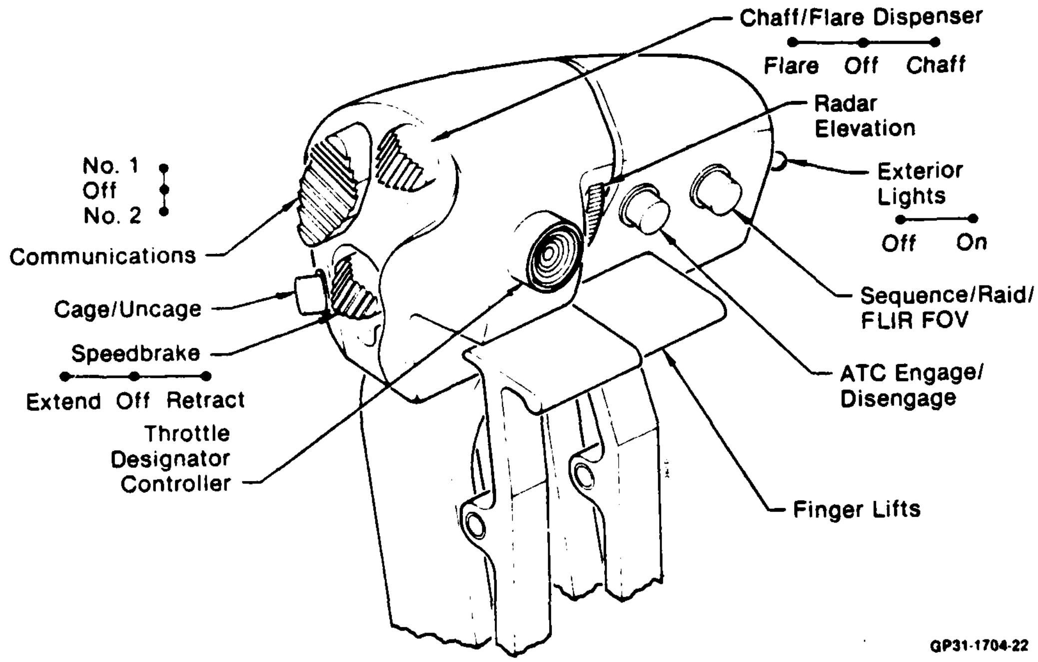


Figure 30. Throttle

3.3.2 Speech Recognition Control (SRC) - The major advantage offered by speech recognition control is that it offers the pilot an additional natural control option when his hands and eyes are already busy. Each word would have a specific meaning just as a switch throw or button push has a specific function.

Speech, or voice recognition control uses specially programmed microprocessors and other dedicated solid state devices to process audio signals and recognize "control" words spoken by the pilot. Ideally, a voice recognition control system would be speaker independent, never make an error, and have an unlimited vocabulary. In practice a system must be "trained" by each user repeating each word in a limited vocabulary and an error is possible. A practical system would have a maximum vocabulary of several hundred words. The training repetitions (approximately 3 to 10 required) could be done once, recorded, and then played into the system as part of the pre-flight preparation. This would be a one time task for the pilot which compares well to the probability of correctly pushing a button or making another mechanical type selection.

In order to be considered a primary control system for critical tasks, a VRC system would require a demonstrated accuracy greater than 99% in the dynamic cockpit environment of an actual mission. Available voice recognizers are capable of a greater than 99 percent accuracy when trained and used by the operator in a non-hostile environment. The projected success rate for such a system when employed in the hostile environment of an advanced fighter cockpit environment (background noise, high G, high stress/workload) is 50-95%. Anticipated hardware improvements should allow VRC to achieve the required levels of performance. Command syntax can also be used to improve system accuracy.

VRC would be a viable control concept for use with the DTACS cockpit. The information presented on the large format display could be reorganized or reformatted using voice commands. Communication with other aircraft or controllers could be controlled using voice commands. VRC supplements other control concepts, but does not totally replace them. Figure 31 presents a typical VRC implementation.

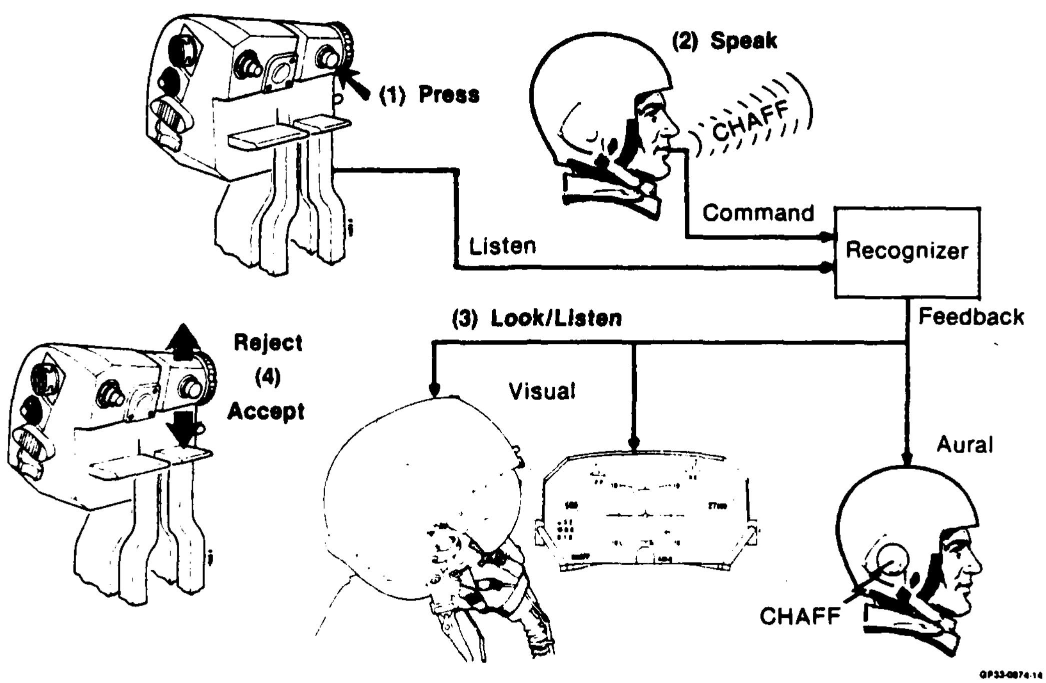


Figure 31. Voice Control Implementation

3.3.3 Touch Sensitive Display Surfaces - The selection of control options by touch is a very natural function. Typically modes and options have been selected by pressing buttons or switches using a finger. The DTACS display panel has few if any switches or buttons. The use of this large touch sensitive display surface will allow the pilot to select options on the display by merely touching the display surface.

Touch sensitive display surfaces can be mechanized in several methods: surface accoustic wave sensors and radiators, LEDs and detectors, membrane switches, and resistive/capacitive surfaces. Figure 32 shows these different mechanizations.

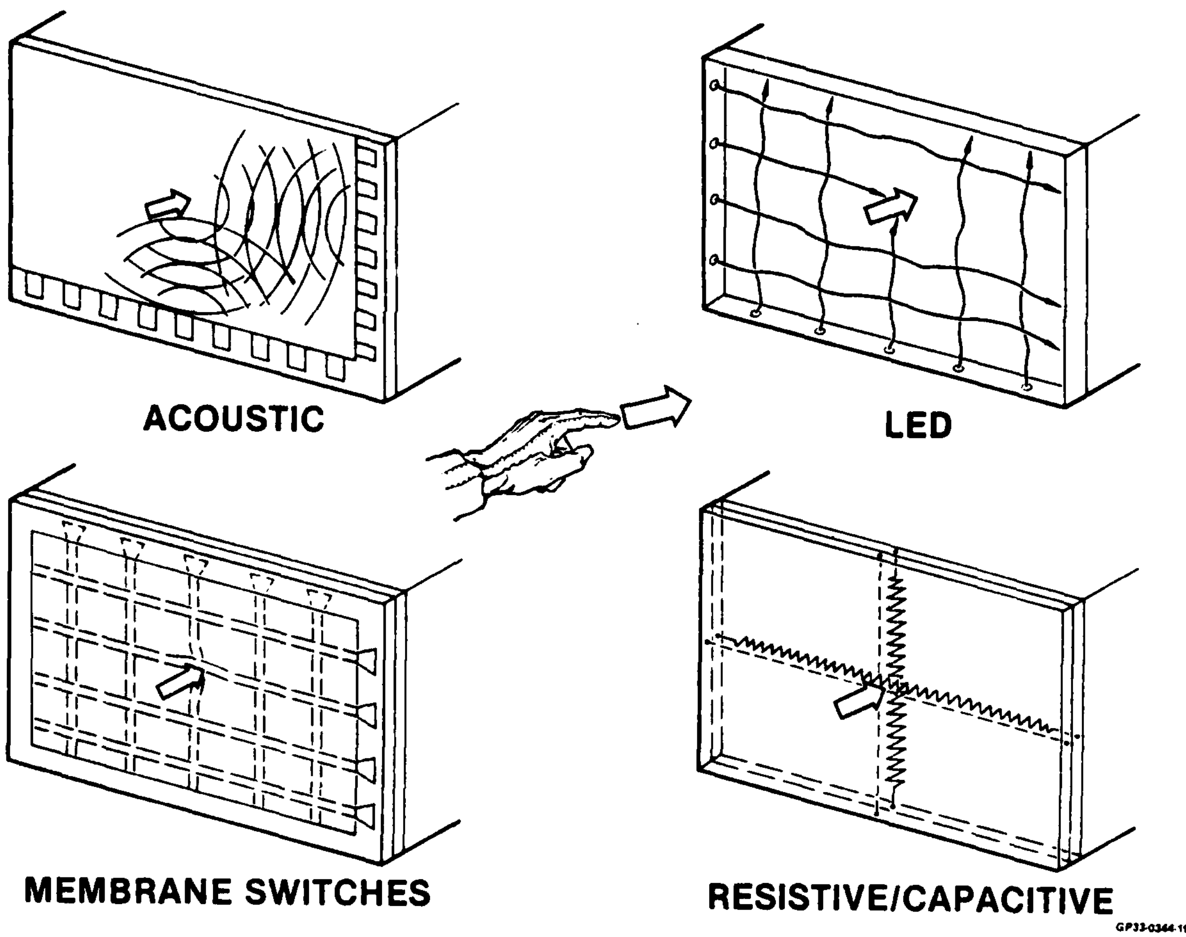


Figure 33. Liquid Crystal Matrix Construction

The accoustic and LED techniques are similar. The presence of a finger on the display surface is detected by the reflection of sound waves or the blocking of IR light waves crisscrossing over the display surface. The exact location is determined by interpreting which sensors are receiving input waves. This determines the vertical and horizontal position of the finger.

The membrane switch and resistive/capacitive methods make the display surface sensitive to touch. The exact position of the finger is determined by which switch is closed or the value of resistance/capacitance elements under the surface.

The touch sensitive display surface is applicable to DTACS because of the dynamic capability of displaying many different display formats on the main display panel. Option selections could be placed anywhere on the display surface as deemed most logical to the particular format and mission segment.

3.3.4 Helmet Mounted Display/Sight (HMD/S) - The HMD/S can be used as a control option selection device. The HMD/S tracks the pilot's head position. The pilot can place the vision reticle of the HMD/S on the desired option presented on the large format display and then select that option by using a HOTAS switch. The HMD/S system would determine where on the display the reticle was positioned and tell the control system to select the option at that position.

3.4 PRELIMINARY AIRCRAFT DISPLAY CONFIGURATION

A preliminary configuration of a large format display system was established. The various technical approaches described in Section 3.1 were reviewed, and the most promising one was selected, a liquid crystal projection system. This display design was done by the Display System Laboratory of the Radar Systems Group of Hughes Aircraft Company under subcontract to MCAIR. Other technologies, such as single crystal projection tubes, also show promise, but were not evaluated in depth for application in cockpit display configuration during this study.

3.4.1 Display System Design - The projection liquid crystal display technology being considered for the DTACS large area color display has been under development at Hughes since the early 1970's. This technology has progressed from the demonstration of the first 100x100-element matrix liquid crystal display in 1973, to the recent demonstrations of a 240 x 320 - element display module with hybridized drive circuitry and projection optical techniques for multi-color and high resolution multi-module displays.

The basic matrix liquid crystal display technology and the optical projection system developments that form the foundation for the DTACS display are summarized in this section.

Matrix Liquid Crystal Module

Figure 33 illustrates the construction of the basic liquid crystal matrix. The liquid crystal material is sandwiched between a semiconductor chip and a cover glass coated with a transparent electrode. The surface of the semiconductor chip is covered with an array of highly reflective electrodes that define the individual picture elements. Beneath the reflective electrodes, this chip also contains one storage capacitor and one switching metal-oxide-semiconductor field effect transistor (MOSFET) for each display element, and row and column bus electrodes.

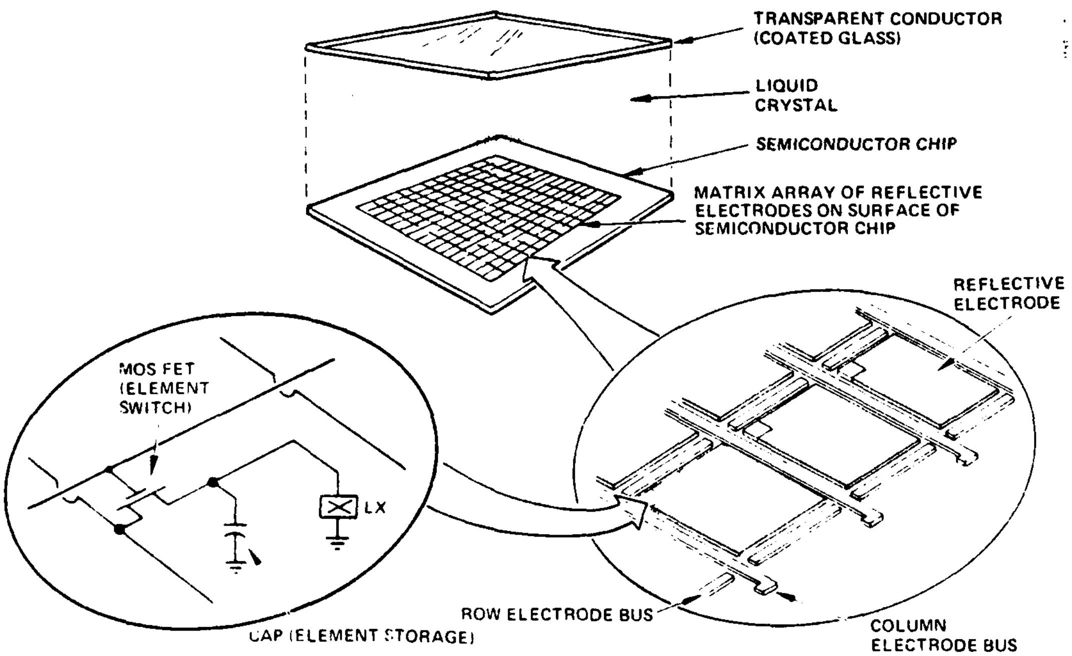


Figure 32. Touch Sensitive Mechanizations

Each column electrode connects to the drain of every MOSFET in its respective column. Similarly, each row bus electrode connects to the gate of each transistor in its corresponding row.

Line-at-a-time addressing is used to form an image on the display. To write one line, voltages proportional to the picture intensities of each element in the line are placed on the column electrodes. A voltage pulse is applied to the appropriate row electrode, the transistors in that row conduct, and each elemental storage capacitor charges to the voltage applied to the corresponding column electrode. The storage capacitors hold sufficient charge to energize the liquid crystal material until the row is rewritten through a periodic refresh. The voltages to the row and column bus electrodes are provided by row and column driver LSI circuits within the hybrid display module.

The liquid crystal material in the display described above modulates incident illumination by dynamic scattering. With no voltage applied to the liquid crystal layer, the liquid crystal material is clear, and incident light is specularly reflected from the mirror electrodes. With a voltage applied, the liquid crystal layer becomes turbid and scatters the reflected light. The visual appearance of a dynamic scattering liquid crystal display is highly dependent on the location of the illumination source and the observer. Thus this type of display is generally used in combination with a viewing optical system and synthetic (as opposed to natural ambient) illumination.

Figure 34 illustrates the use of a dynamic scattering liquid crystal display with a simplified version of the optical system used in all Hughes liquid crystal projection displays. Light from a well-collimated illumination source is focused to a small point, reflected towards the liquid crystal display, and collimated by the field lens in front of the display. The light which is specularly reflected from unenergized display elements is refocused by the field lens and passes through a small aperture. This light is then gathered into another lens and projected as a bright spot on the diffusing screen. On the other hand, the scattered light from energized display elements is almost completely blocked by the aperture and the corresponding areas on the diffusing screen appear dark.

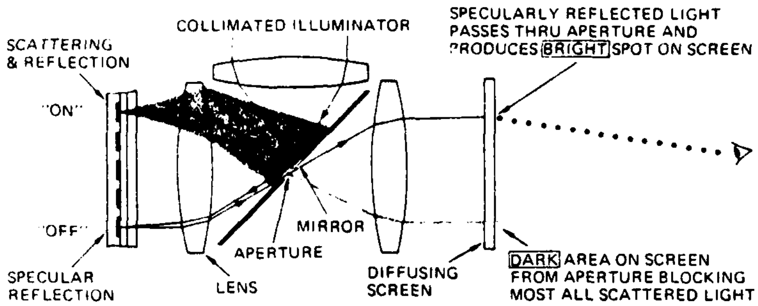


Figure 34. Basic Liquid Crystal Projection Display System

Projection Displays

The first demonstration of a projection display system using a matrix liquid crystal image source occurred in 1978 as part of the Integrated Head-Up Display Program for AFWAL. Since that time, optical projection systems using multiple liquid crystal modules have been developed to provide high resolution and multi-color displays.

A basic full-color projection module has been defined. This module, as illustrated in Figure 35 consists of a projection lens, a beam-splitter prism that separates the incoming light into red, green, and blue primary colors, and three of the previously described hybrid liquid crystal modules. The mechanical and optical interfaces to the projection lens have been selected such that the magnification factor of the lens can be changed without modification to the other components.

One particularly important feature of the projection module is the use of a non-coherent fiber optic bundle to introduce the light from the illuminator. The fiber optic bundle provides mechanical and optical isolation between the illuminator and the projection module during shock, vibration, and temperature variations. In addition, through the use of branched fiber optic bundles, more than one illuminator can be used to provide light to a given projection module, and each illuminator can provide light to more than one projector. This feature allows the use of redundant illuminator modules for increased display brightness and reliability, and provides for degraded mode operation of the display in the event of a failure in one illuminator.

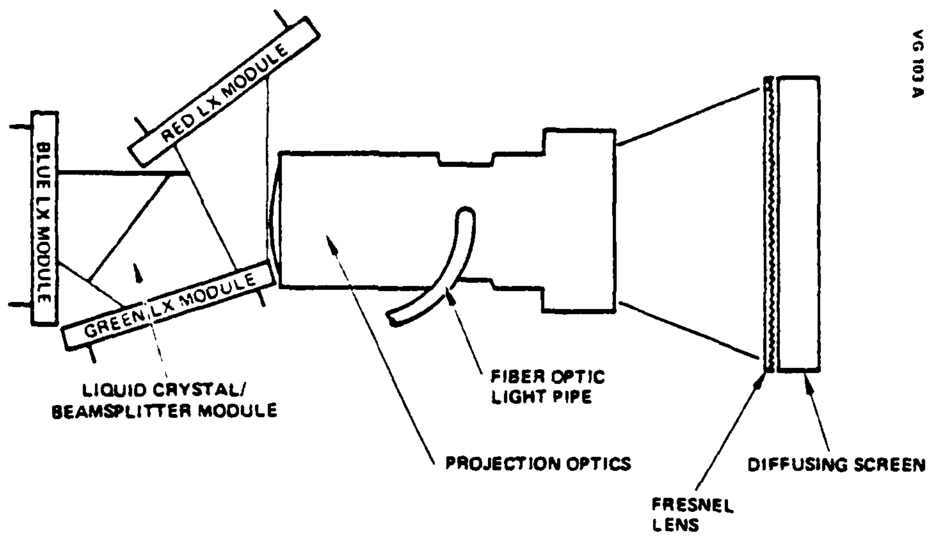


Figure 35. Basic Full-Color Projection Module

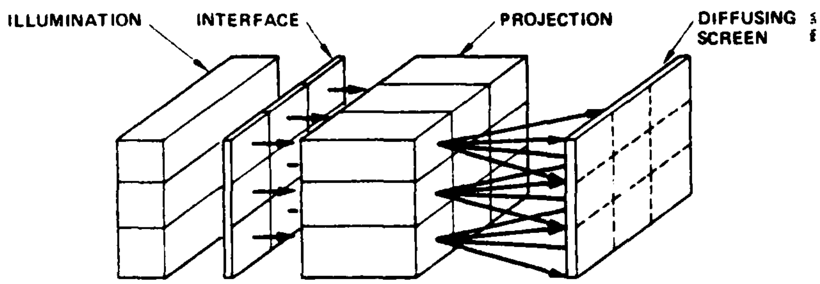
Large Area Color Display Architecture

One objective of this study is to define an architecture for a full color display having an area of up to 18 x 24 inches and resolution of up to 1800 x 2400 elements for the DTACS system. The size, weight, power consumption, interface, reliability and maintenance requirements for this display must be compatible with the DTACS program objectives and suitable for eventual installation in an advanced single-seat aircraft, and the cost and logistics support requirements of the display must be consistent with the DTACS program objectives.

A highly modular display system architecture based on the previously described projection liquid crystal technology is being considered for this application. As illustrated in Figure 36, the architecture under consideration consists of four basic module types - - projection, illumination, diffusing screen, and interface. These modules, and the mechanical structure on which they are mounted, are discussed in the following subsections.

Projection Module

A basic three-color projection module, consisting of a color-selective beam-splitter, three liquid crystal matrices, and a projection lens, was previously



• ABUT IMAGES FROM MANY PROJECTION MODULES

• COMMON DIFFUSING SCREEN

• REDUNDANT ILLUMINATION MODULES

DISPLAY IMAGE SIZE, RESOLUTION, PERFORMANCE DETERMINED BY NUMBER, NOT TYPE OF MODULES

Figure 36. Modular Projection Display Block Diagram

shown in Figure 35. A similar projection module structure, with re-designed components, will be used in the DTACS display. The primary independent parameters available to the DTACS display designer will be the number of projection modules used to achieve a given display image size, the speed (f#) of the projection lens, the size and resolution of the image area on the liquid crystal matrix, the size of the hybrid liquid crystal module, and the size of the aperture within the projection optics. These parameters will then determine the display length, projected image size, resolution, and visual performance.

The major trade-off in the design of any large area display will be the selection of the number of projection modules. This selection will have a major impact on the reliability, cost, length, and visual performance of the display.

Labor is the largest component of the costs of the beamsplitter and projection lens components and of the projection module assembly and test. These costs do not, to the first order, vary with the module size. Thus these components of the complete display cost will increase in proportion to the number of projection modules. On the other hand, the cost of the liquid crystal matrix is highly dependent on the size and resolution of the matrix image. The total cost of the liquid crystal matrices will decrease as the number of modules per display is increased.

The net effect of the number of projection modules on display cost is shown qualitatively in Figure 37. The cost of the display is minimized for a fixed number of modules for any given total display image size and resolution. The display cost rises slightly if more than the optimum number of modules are used, and may rise dramatically if a few, very large liquid crystal matrices, are required.

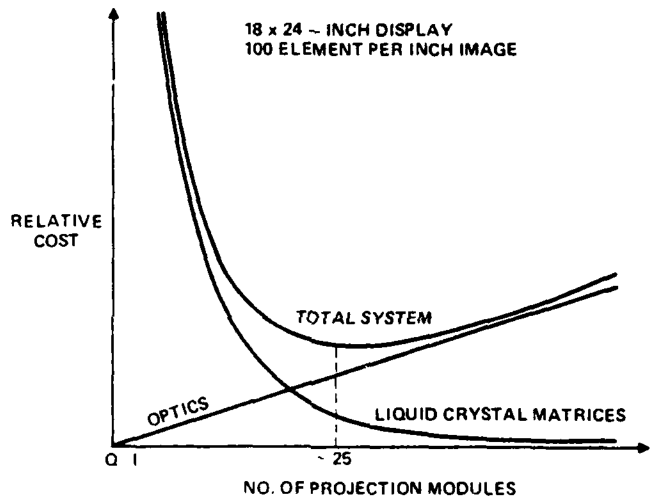


Figure 37. Display Cost Depends on the Number of Projection Modules

The overall length from the diffusing screen to the back of the rear liquid crystal module is approximately equal to the length of the projection module plus the projection lens f# times the diagonal of the image projected from each module. For a given display image size, increasing the number of modules reduces the image size projected from each module and thus reduces the overall display length. The relationship between number of modules and the length of a 18 x 24 inch display is shown in Figure 38.

The amount of light that can be collected from an illumination source and directed to a single projection module is a complex function of the number of

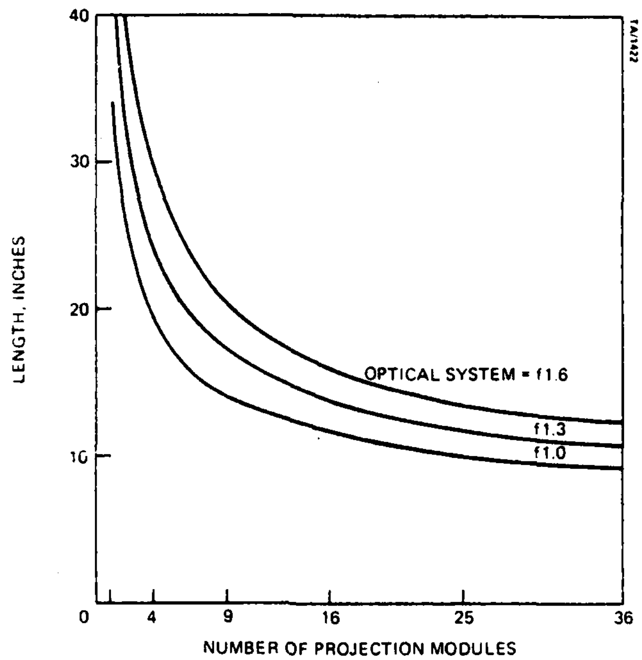


Figure 38. Length of an 18 x 24 Inch Display

projection modules, the number of illumination modules, and the detailed design of each module type. For a fixed diffusing screen size, the brightness of the display will increase significantly as the number of projection modules is increased and either brightness or length, rather than cost, considerations may define the minimum number of modules acceptable for a given display image size.

Projection Lens Speed

The speed of the projection lens has a major impact on image distortion and display length. For a given number of lens elements, the distortion in the projected image varies approximately as the inverse of the fourth power of the lens f#. The need to register the images from multiple projection modules without objectionable discontinuities will define the maximum amount of distortion allowable, and thus define the minimum acceptable lens f#. As previously stated, we feel that a lens with nine or ten elements and an f# of 1.3 can be used in the

DTACS system. A slightly lower f# might be obtained with the introduction of additional lens elements.

As was shown in Figure 38, the length of the optical path from the diffusing screen to the rear liquid crystal module is approximately equal to the length of the projection module plus the lens f# times the diagonal of the image projected from each module. Thus the physical constraints on the display unit size will define the maximum f# for a given image size per projection module.

The projection lens speed also effects the display brightness uniformity and cost. Minimum cost and maximum uniformity can be obtained by selecting as a large an f# as possible within the limits set by distortion and length considerations.

Liquid Crystal Module Design

One important consideration in the design of a modularized large-area display is that the projection modules must be maintainable and replaceable without mechanical interference with the adjacent modules. This consideration can be satisfied if the center-to-center spacing (and thus the projected image size) of the modules is slightly larger than the cross section of the modules. As can be seen from Figure 35, the height of the projection module is determined by the angles at which the liquid crystal matrices are mounted on the beam-splitter, and the size of the hybrid liquid cyrstal module. To allow room for the mounting of driver circuits around the perimeter of the liquid crystal matrix, the minimum size of the hybrid module will be approximately one-inch larger, on each axis, than the size of the liquid crystal image area.

Given that the projected image size must be equal to or greater than the cross section of the projection module, the minimum magnification factor of the projection lens is given by the ratio of the projection module height to the height of the image on the liquid crystal matrix. Assuming a resolution density of 100 element per linear inch in the projected image, the minimum resolution density on the liquid crystal matrix will be 100 times the magnification factor, and the minimum resolution of the module will be 100 times the projection module height.

Assuming that the height of the hybrid module is one-inch larger than the liquid crystal matrix image height, the relationships between the height of the image on the liquid crystal matrix, the height of the projection module, and the minimum magnification factor are shown in Figure 39 for a display with 100 elements per linear inch in the projected image. The minimum resolution and the resolution density at the liquid crystal matrix are 100 times the projection module height and magnification factor, respectively.

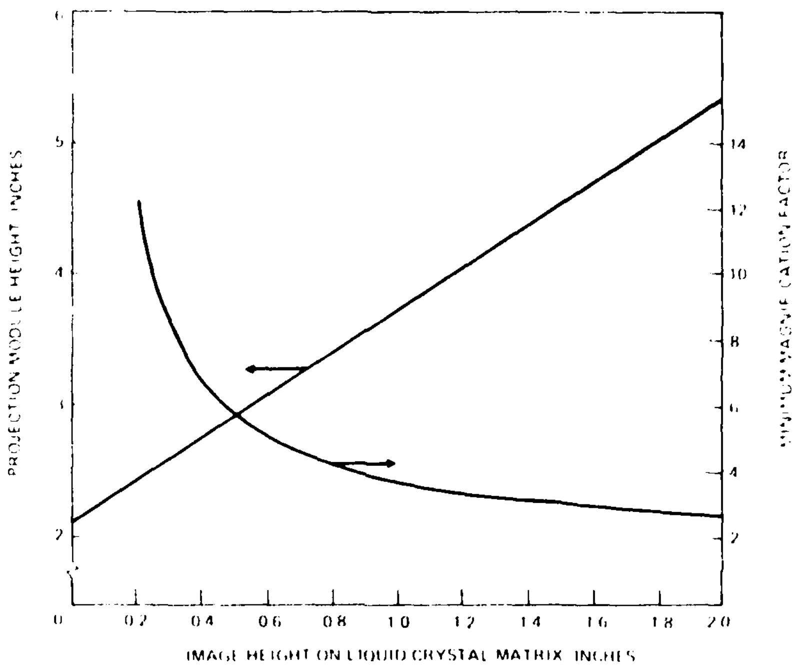


Figure 39. Projection Module Height and Minimum Magnification Factor for 100 Element-Per-Inch Full-Color Display

The hybrid liquid crystal display matrix module currently being developed has an image height of 0.75 inches. A full-color projection module using this liquid crystal device would have a minimum height of 3.35 inches and a magnification factor of 4.5:1. Using the current liquid crystal matrix, the resolution of the projected image would be 71 elements per inch. A 0.75 x 1.0 inch, 360 x 480 element module would be required to provide 100 elements per inch in the projected image.

An alternative to the development of a higher resolution liquid crystal matrix would be to use a simplified projection module architecture, which uses only two liquid crystal matrices. This "2-color" projection module would be smaller in length and height than the "3-color" module previously described. The smaller height of the 2-color module allows the use of lower resolution liquid crystal matrices. The relationship between the height of the image on the liquid crystal matrix, the height of the projection module, and the minimum magnification factor are shown in Figure 40.

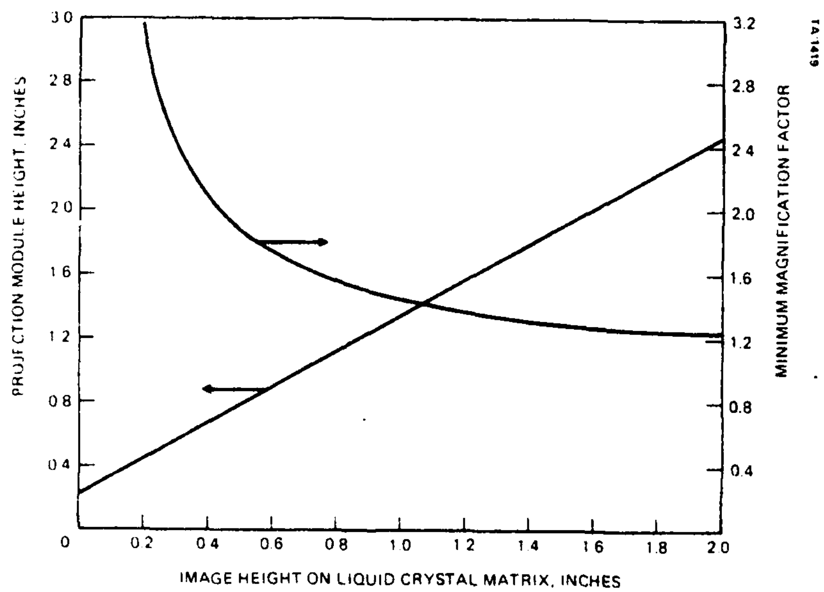


Figure 40. Projection Module Height and Minimum Magnification Factor for 100 Element-Per-Inch Two-Matrix Display

A 2-matrix projection module which uses a single beamsplitter to separate the red and green components of a yellow light source has been developed. This projection module generates red/yellow/green imagery. A possible alternative configuration would use a white light source and a single beam-splitter to direct the green light to one liquid crystal matrix and the red and blue components to the second liquid crystal device. The second liquid crystal matrix would include a patterned red/blue absorptive filter that allowed the single module to generate both red and blue images at half of the resolution of the green image. This approach might be used to construct a more compact, less expensive, full-color display which provided high resolution in only one display color.

The relationships between minimum liquid crystal matrix resolution and image size for both 2- and 3-color projection modules are plotted in Figure 41. Also plotted are the size/resolution combinations that have been developed by Hughes. This figure shows that, while the full-color 100 element-per-inch display will require an advance in the state-of-the-art in matrix liquid crystal devices, either the 80 element-per-inch or 2-matrix display can use current technology. A 360 x 480 element, 0.75 x 1.0 inch, matrix suitable for modular high resolution fullcolor displays is under consideration for other applications.

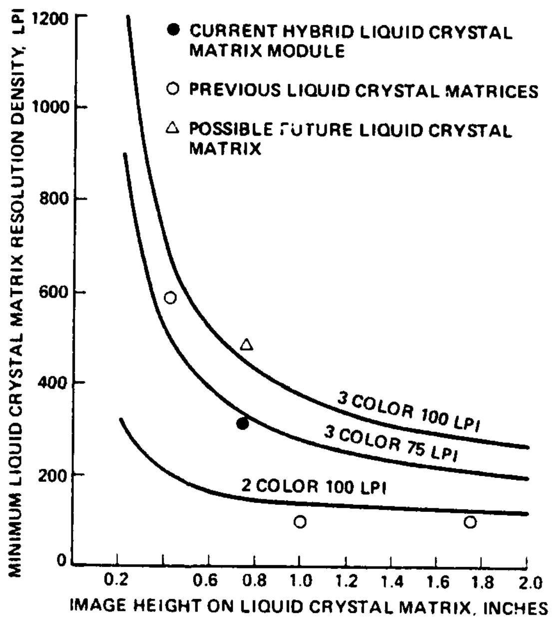


Figure 41. Liquid Crystal Matrix Resolution vs Image Size

Aperture Size

A key feature of this modular display approach is the use of a fiber optic light pipe to conduct the light from the illumination sources to the projection modules. Within the projection module, the end of the fiber optic serves as a point light source. The projection lens directs the light from this point source to the liquid crystal modules. After the light is reflected from the liquid crystal matrices, the lens forms an image of the point source on a small aperture. The ratio between the fully bright and fully dark states, or dynamic range, of the projection module is determined by the size of the fiber optic light pipe and the size of the aperture. This relationship is shown in Figure 42. In this figure, the size of the fiber optic is given as an angular subtense; the actual diameter of the fib r is given by the tangent of the angular subtense times the focal length of the projection lens.

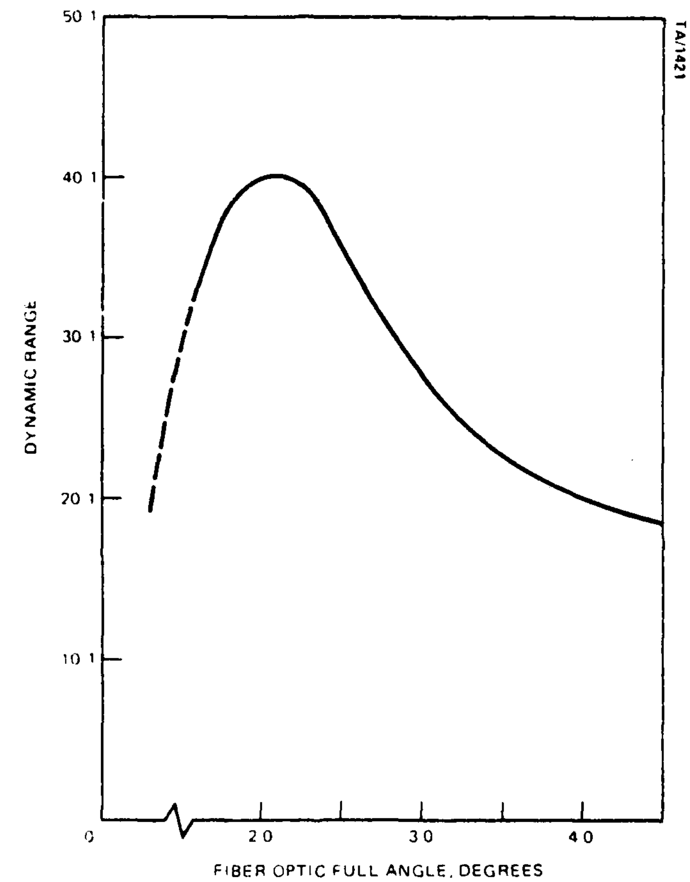


Figure 42. Dynamic Range of the Projection Module

The dynamic range of the projection module, as shown in Figure 42, is one factor that determines the contrast ratio of the complete display. Other factors which effect contrast ratio including the diffusing screen characteristics and the amount of light collected in the illuminator modules, will be discussed in the next sections.

Diffusing Screen

The diffusing screen module consists of the diffusing element, contrast enhancement filters, and any required field lenses. The diffusing screen module developed for small-area color projection displays uses a holographic diffusing element, a fiber optic faceplate that functions as an angle-restrictive filter, an absorptive glass contrast enhancement filter, and field lenses on both sides of the module. This screen module provides very high, uniform, gain, but is not suitable for very large displays do to the difficulty in fabricating the large-area diffusing element, the high cost of the large-area fiber optic faceplate, and the weight of the entire assembly.

For large area multi-color displays, a screen module similar to that developed on the Head-Up Display Technology Demonstration program can be used. A version of this screen, designed for use with four projection modules, is shown in Figures 43 and 44. The screen consists of a precisely segmented Fresnel field lens which

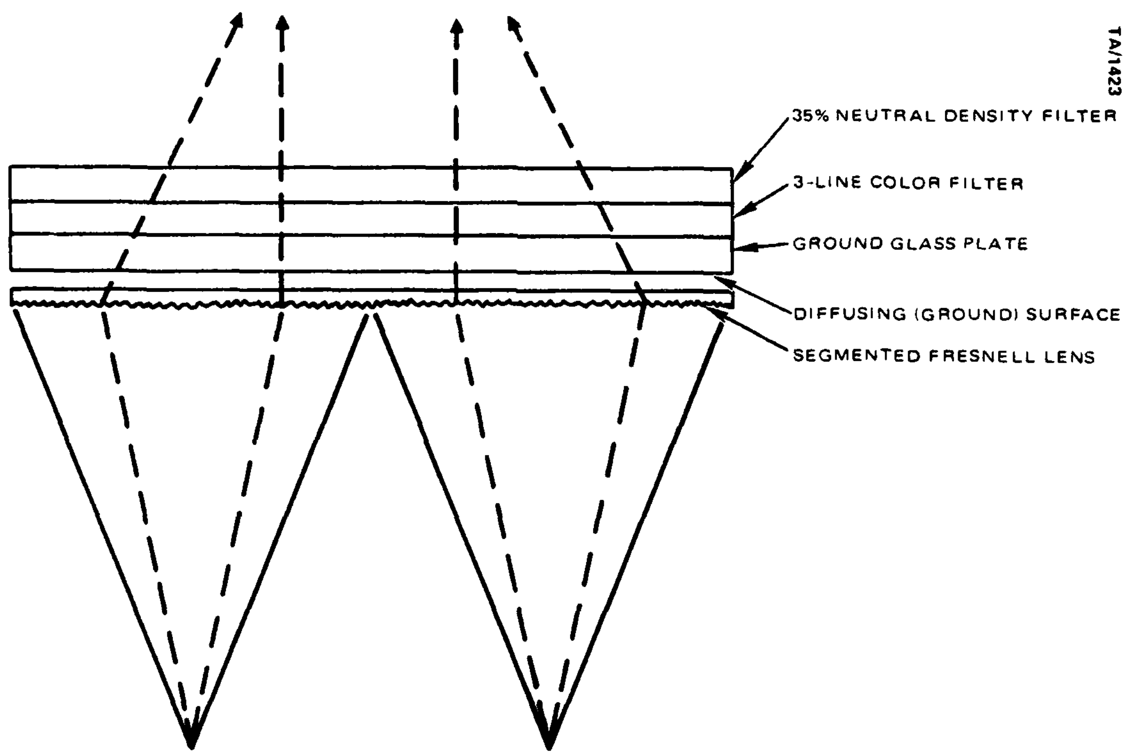


Figure 43. Diffusing Screen Module

directs the light from the projection module towards a common exit pupil, a ground glass diffusing surface, and a contrast enhancement filter. The contrast enhancement filter for a large area color display will consist of a "3-line" color selective filter similar to that used on color CRT's and a 35% neutral density filter. This screen structure can provide a gain of 4 (including the losses in the contrast enhancement filter) and has a maximum diffuse reflectivity of 0.6%.

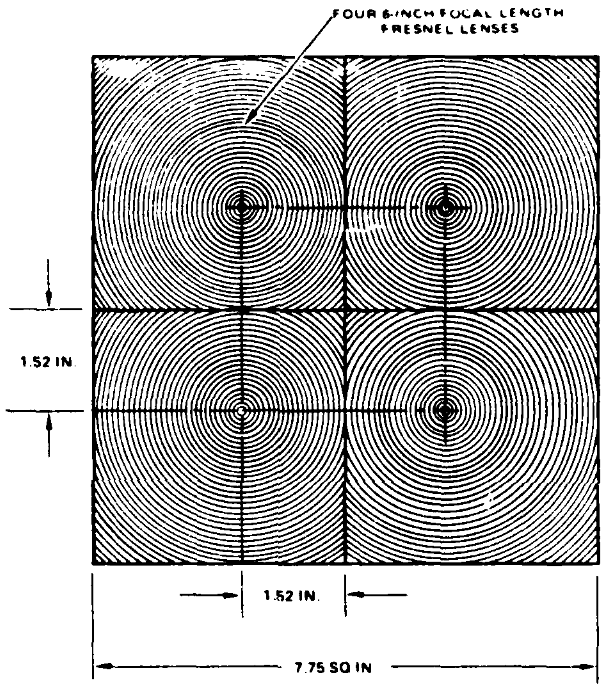


Figure 44. Fresnel Field Lens, Direct Light From Four Projection Modules to Single Exit Pupil

Illumination Module

Each illumination module consists of three separable sub-modules - - a lamp house containing a Xenon arc lamp and optical elements, an ignitor which provides the high voltage ignition pulse to start the arc lamp, and a low voltage power supply which energizes the lamp after ignition. The illuminator modules require liquid cooling and 180 watts of primary aircraft power per module. The optical design of the lamp house, illustrated in Figure 45, is composed of an arc lamp with an internal parabolic reflector, UV and IR filters, a focussing lens, a variable

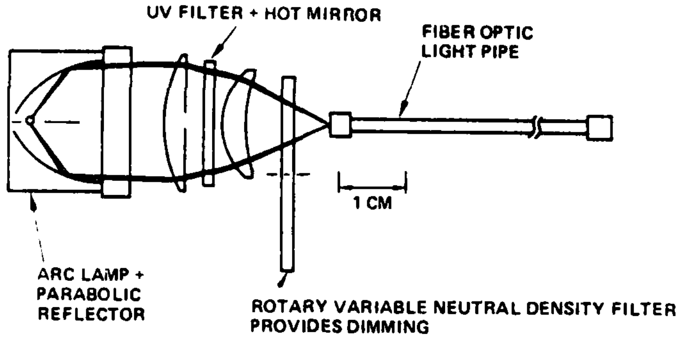


Figure 45. Lamp-House Optical Design

neutral density filter which provides brightness control, and a fiber optic light pipe that conducts the light to the projection modules.

The amount of light collected at each lamp-house is determined by the age of the arc lamp and by the angular subtense of the fiber optic light pipe. The relationship between these parameters is shown in Figure 46. The nominal end-of-life of the arc lamp is after 1000 hours of operation, at which point the light output has fallen to about 45% of its initial value.

To ensure even illumination of the liquid crystal matrices in the projection modules, the f# of the focussing lens in the lamp-house must be the same as that of the projection lens. The physical diameter of the fiber at each projection module is given by

(1) $dp = (f\#)\,(D)\tan(a)$

where dp = the fiber diameter at each projection module,

D = the diagonal of the liquid crystal matrix,

a = the angular subtense of the fiber at the liquid crystal matrix.

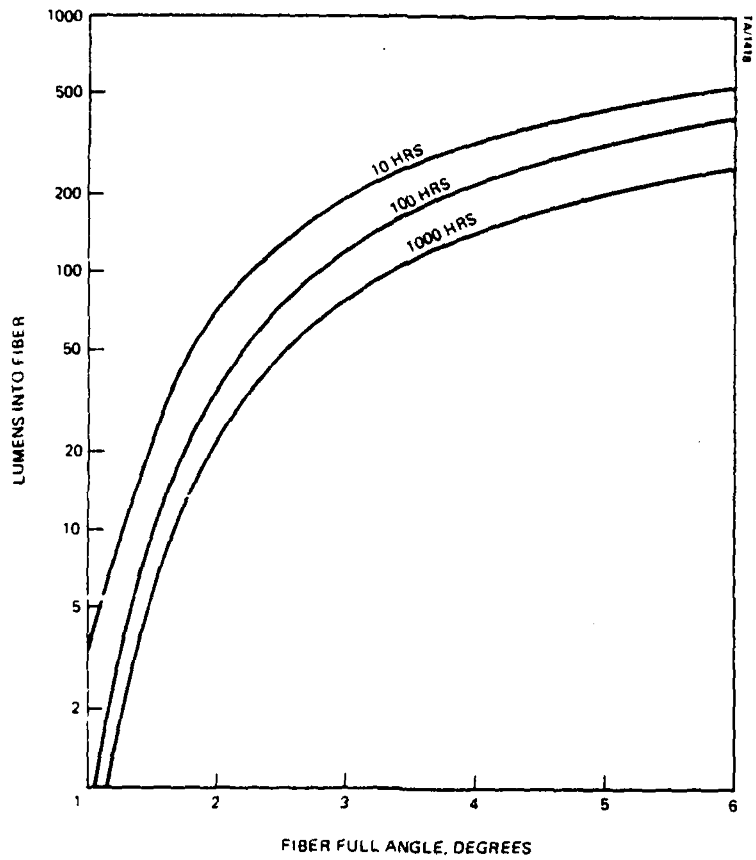


Figure 46. Lamp-House Output Varies With Lamp Age and Fiber Diameter

The physical diameter of the fiber at each lamp house is given by

(2) $dl = (dp)\ M/N$

where dl = fiber diameter at lamp house,

M = the number of projection modules in the display,

N = the number of illumination modules.

The angular subtense of the fiber at the lamp house is given by

(3) $b = \arctan(dl/(f\#)(25))$

where b = the angular subtense at the lamp house,

25 = the diameter of the focussing lens in millimeters.

Since both a and b are small angles,

(4) $b = (a)\ M/N\ (D)/25.$

Equation (4), the data presented in Figure 42, the characteristics of the diffusing screen, and the other known parameters (such as the efficiency of the beam-splitters and optical elements) can be used to calculate the performance of the large area projection display as a function of a, M, N, and the projected image size. The results of these calculations, assuming a 10000 foot candle diffuse ambient and a 360 x 480 element liquid crystal matrix projected to a 3.6 x 4.8 inch image, are shown in Figure 47.

The data shown in Figure 47 demonstrates several interesting points. First, the brightness of a large area liquid crystal projection display does not vary in proportion to the inverse of the display area as might be expected. In fact, increasing the display size from 3.6 x 4.8 inches to 7.2 x 9.6 inches (from one to four modules) actually results in an increase in display brightness and contrast in some cases.

A further increase in display size to 14.4 x 19.2 inches results, in all cases, in a decrease in display contrast by a factor of less than two. A second interesting feature is that for a one or four module display, increasing the number of illumination modules may actually decrease the display brightness and contrast. Third, as may be derived from equation (2), arbitrarily large displays of constant performance can be obtained by keeping the ratio of projection modules to illumination modules constant.

Interface Circuitry

The liquid crystal matrix devices scan in a left-to-right, top-to-bottom, 60 hertz, non-interlaced raster format. The interface to a large area display with N projection modules is essentially the same as that to N R-G-B CRT displays. A blanking period of about 10 microseconds, similar to the horizontal blanking interval in a standard video signal, is required between adjacent video lines. A vertical blanking period is not required.

The typical input signals to a large area projection display would be element clock, vertical synchronization, horizontal synchronization, and an analog or digital video signal for each liquid crystal device (3 signals per projection

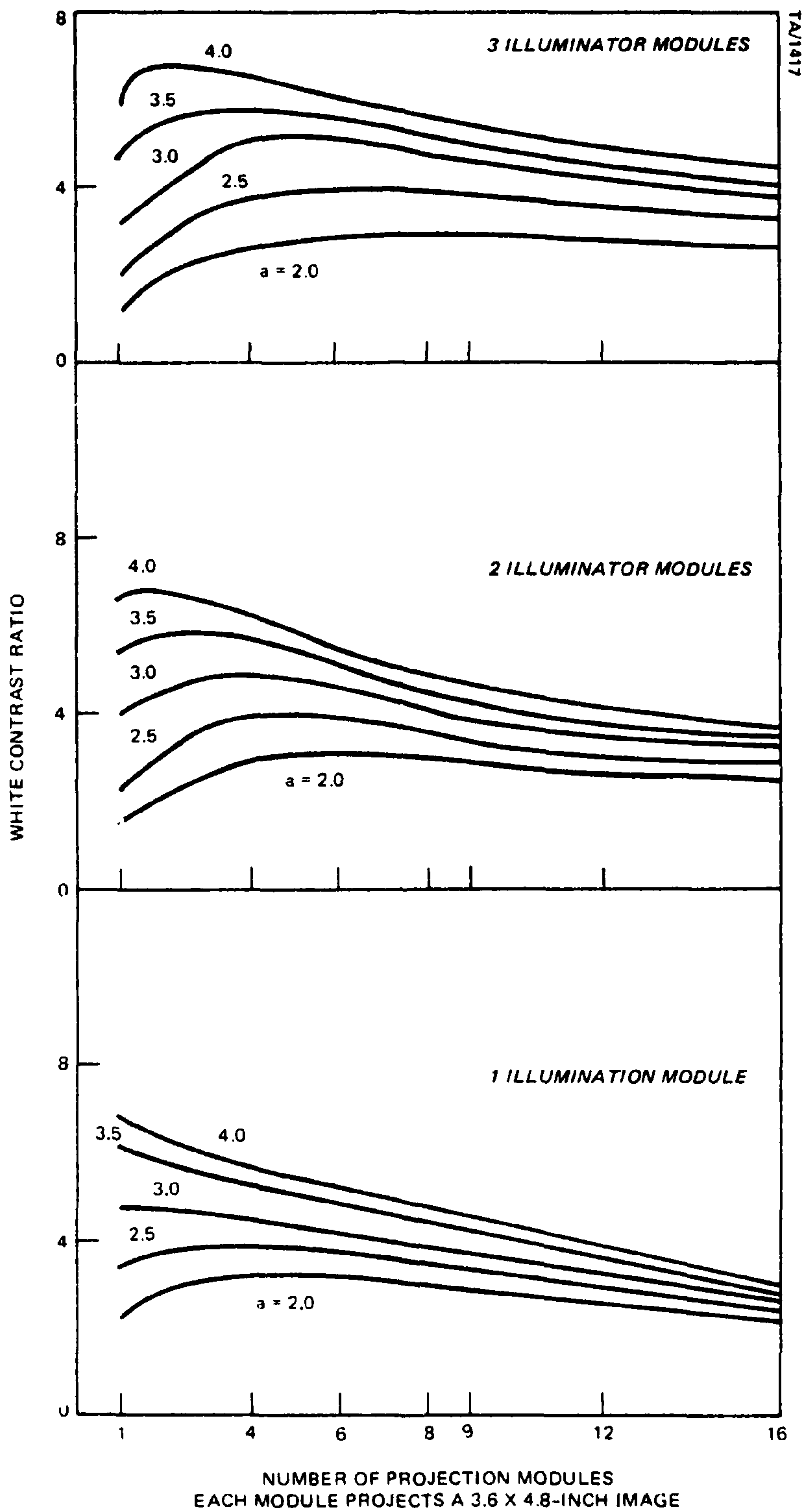


Figure 47. Display Contrast as a Function of Area (Number of Projection Modules)

module). These input signals can be converted into the drive signals for the liquid crystal modules with about 20 small scale integrated circuits (or one custom LSI circuit) per projection module.

Mechanical Structure and Maintainability

The mechanical structure for a large area projection display must be designed with the following considerations:

a) The large size and weight of the display dictate that the mechanical structure be essentially incorporated into the airframe. All maintenance must be performed without removing the entire display from the aircraft.

b) The illumination modules must be readily accessible for replacement of the arc lamps, ignitors, blowers, and power supplies when required.

c) The projection modules, though not requiring frequent replacement, must be replaceable without requiring a complete re-alignment of all modules.

d) The projection modules must be precisely positioned with respect to the diffusing screen and with respect to each other during vibration, shock, and temperature change.

A design concept which is believed to be compatible with these requirements is shown in Figure 48.

The basic mechanical structure consists of three planes. The front plane contains the diffusing screen and functions as the front panel of the unit. The projection modules are mounted through the center plane. This structure holding the projection modules is shown as a flat plate in Figure 48. In actual practice, a three-dimensional structure with stiffening ribs will be required to provide the necessary rigidity under vibration. The projection modules are pre-adjusted during manufacture to provide a consistent image size and are aligned on pins inserted in the mounting structure. Thus one module can be replaced without extensive alignment operations. The front panel of the display would be hinged to allow access to the projection modules.

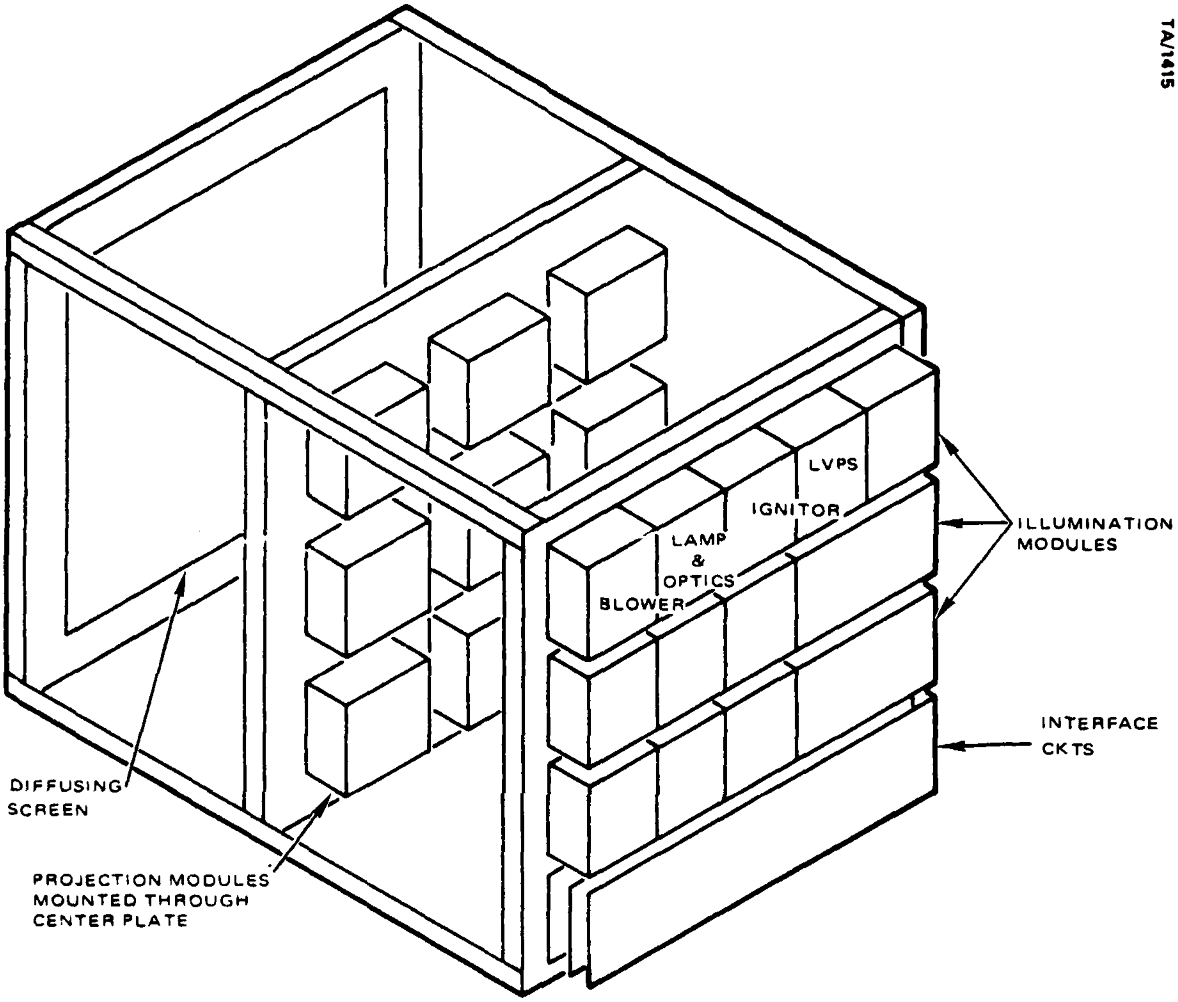


Figure 48. Large Area Projection Display Physical Design

The illumination modules and interface circuitry are mounted on the rear plane and maintained through access doors in the aircraft. Since the arc lamps will require replacement at fixed intervals, the unit mounting mechanism must allow access to the illuminators. Alternatively, the illumination modules could be located in a second unit in a more accessible location in the aircraft. Remote mounting of the illuminators would require connectors in the fiber optic light pipes which would reduce the brightness of the display slightly.

3.4.2 Risk Assessment - There are three main areas of risk associated with the DTACS display concept. They are: 1) the Display Device; 2) Human Factors; and 3)

Supporting Data Base. The following paragraphs provide further details on each area of risk.

Display Device - There are three areas of risk associated with the display device itself. The first area of risk is the development of the high resolution liquid crystal module. The second area is the development of low distortion lenses for use in the projection optics. The third area is the mechanical structure - its stability in vibration (necessary for convergance, color purity, etc.). Each of these three areas must be analyzed to eliminate or reduce its contribution to the overall risk level.

Human Factors

The risk in the human factors area is workload. Workload is defined as a combination of time load, mental effort load, and psychological stress load. Time load is a measure of the time requirements for a task. Mental effort load measures the amount of conscious mental effort required to perform a task. Psychological stress load is a measure of the confusion, anxiety or frustration associated with a task. The workload using the DTACS display concept will need to be evaluated to determine its value during various phases of missions.

This would involve both the subjective assessment of workload as well as quantitative measures. The DTACS concept involves methods to improve information presentations and control techniques. Verification of the utility of these techniques as well as their refinement during the development process will necessitate detailed examination of the visual process. Eye tracking devices would provide quantitative measures of visual search and data acquisition efficiency. Examination of the state of a subject's visual acquity, focusing process, and light adaption levels while engaging in HUD, HDD, HMD/S, and external visual scan and fixation should be accomplished. Mental processing of information should be examined by the observation of subjects in realistic simulated combat scenarios. All other tasks - intellectual, motor and sensory - should also be examined for periods of competing stimuli presented to the pilot or simultaneous manipulative task requirements.

In summary, all aspects of pilot performance should be examined during laboratory studies, part task pilot performance studies, and full, critical mission simulations.

Supporting Data Bases

The other risk area is in the development of the supporting data bases necessary for the fusion process of information for a large format display. Systems such as integrated automatic flight control systems, automatic terrain following/terrain avoidance, automatic target recognizers and, digital land mass data based map generators and navigators will all need to be available to fully utilize the fused large format display.

Many of the elements of the DTACS display concept are still in the very early stage of development. The risk of developing this type of system decreases as each of these supporting systems becomes developed and operational. The assessed risk associated with DTACS to have a fully operational production system in 5 years is high, medium risk over a period of seven years and low if stretched out to a 10 year program.

3.4.3 Reliability - The expected reliability of large-area color projection displays was calculated using the best available data. The following assumptions were used in these calculations:

a) The reliability of the interface circuitry, low voltage power supplies, and miscellaneous components was based on estimated component counts, MIL-HDBK-217, and experience with similar hardware.

b) The reliability of the hybrid matrix liquid crystal display modules was calculated using MIL-HDBK-217. The failures within these modules have been divided into two categories - complete failures which result in a loss of a significant portion of the module display area, and line failures which result in the loss of a single line within the display area. Line failures are not counted in the MTBF calculations (A single line within one liquid crystal matrix represents less than 0.004% of the content of an 18 x 24 inch display). Degradation failures within the liquid crystal material, which will occur after 10,000 to 30,000 hours of operation depending on temperature, were assumed to be beyond the life of the equipment and were ignored.

c) Periodic replacement of the arc lamps at 1000 operating hour intervals was assumed. The failure rate of the lamps was based on a manufacturer's estimate that about one lamp in eight would fail before 1000 hours.

d) Periodic replacement of the ignitor modules at 8000 operating hour intervals was assumed. The failure rate of the ignitors was based on Hughes Aircraft reliability history data on another program. This data indicated that a significant fraction of the ignitors would fail within that period.

e) Since the output power of the low voltage power supply and the area of the diffusing screen are both proportional to the number of projection modules, the failure rates for the power supply and screen were assumed to also be proportional to the number of projection modules.

f) Closed cycle liquid cooling has been assumed. Failures of the aircraft cooling system are not considered here.

The calculated failure rates of the projection and illumination modules are summarized in Figures 49, and 50 respectively. If the failure rates of the illumination and projection modules are simply summed, the MTBF of an 18 x 24 inch display using 8 illumination modules and 25 projection modules would be only 400 hours, which is three to four times the MTBF of current fighter instrument panels. This simple MTBF number does not, however, reflect the true reliability of the display as it reflects aircraft availability and mission success probability. Conservative estimates of reliability (MTBF) between unscheduled maintenance actions should be more than five times that of present production aircraft instrument panels.

Figure 51 shows block digrams of an 18 x 24 inch color projection display which illustrates, from the reliability point-of-view, the high degree of redundancy within the display. The aircraft would be available (a mission could be started without prior maintenance) if the following portions of the display are functional:

a) Both low voltage power supplies.

b) Any six of the eight illumination modules.

c) The nine projection modules at the center of the display.

Component	Quantity Per Module	Total Failures Per 1,000,000 Operating Hours	
		Complete	Single-Line
Liquid Crystal Matrix	3	10.5	19.5
Beam Splitter Prism	1	1.0	
Projection Lens	1	1.0	
Mechanical Structure	1	0.5	
Subtotal		13.0	19.5
Diffusing Screen	*	0.1	
Interface Circuitry	*	3.6	
Low Voltage Power Supply	*	3.0	
Total Failures Per Projection Module		19.7	19.5

Note:

*These components are not part of the projection module, but failures in these components will be proportional to the number of projection modules.

Single-line failures in liquid crystal modules are not counted in the display system MTBF calculations.

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Figure 49. Projection Module Reliability

Component	Quantity Per Module	Total Failures Per 1,000,000 Operating Hours
Xenon Arc Lamp	1	125.0(1)
Ignitor	1	92.2(2)
Lamp Power Supply	1	27.8
Optics	1	1.0
Mechanical Structure	1	1.0
Total Failures Per Illumination Module		247.0

Notes:

(1) Assumes replacement of the arc lamps at 1,000 hr intervals.

(2) Assumes replacement of the ignitor module at 8,000 hr intervals.

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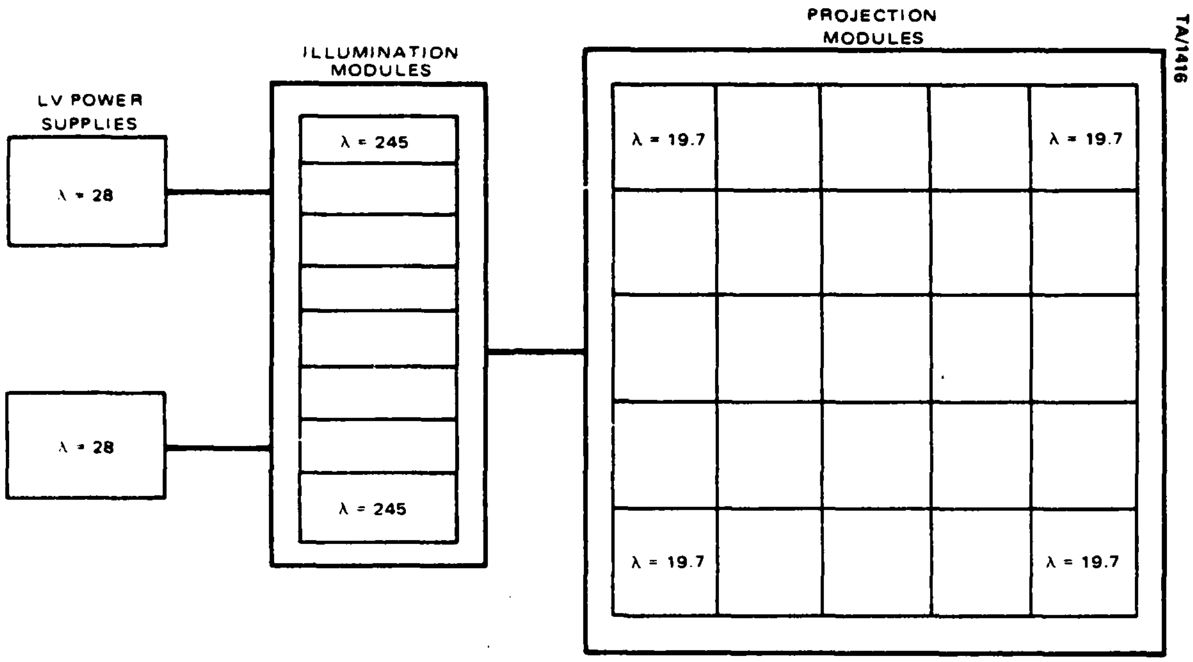
Figure 50. Illumination Module Reliability



λ = FAILURE RATE (10^{-6})

ANY FAILURE				
λ = 2(28)	+	8(245)	+	25(19 7) = 2508 MTBF = 399 HRS
CRITICAL FAILURE				
ANY LV SUPPLY	OR	3 OF 8 ILLUMINATION MODULES	OR	ANY OF CENTRAL NINE PROJECTION MODULES
3(28)	+	245(2 3)	+	9(19.7) = 825 MTBF = 1212 HRS
MISSION FAILURE				
BOTH LV SUPPLIES	OR	6 OF 8 ILLUMINATION MODULES	OR	ANY OF CENTRAL NINE PROJECTION MODULES
18 7	+	245(.82)	+	9(19.7) = 397 MTBF = 2519 HRS

Figure 51. Reliability Block Diagram for 18 x 24 Inch Color Projection Display

The calculated mean-time between aircraft unavailability due to the color projection display is 1200 hours.

To successfully complete a mission, only the following portions of the display must be operational:

a) One of the two low voltage power supplies.

b) Any four of the eight illumination modules.

c) The nine projection modules at the center of the display.

In this case, the information content and visual performance of the display will be adequate to present all mission and survival critical information. In fact, the total information content and visual performance of the degraded projection display will be comparable to those achieved with the three or four CRT displays used in current cockpits. The calculated mean-time between mission failure due to the color projection display is 2500 hours.

To present the minimum navigation, flight data, and aircraft status information required to fly the aircraft, the following portions of the display must be functional:

a) One of the two low voltage power supplies.

b) Two of the eight illumination modules (symbology will be presented in the brightest display color only).

c) Any three of the twenty-five projection modules.

Except in case of extensive battle damage to the display system, or in case of loss of the aircraft electrical power or cooling system (both of which are presumed to be highly redundant), and assuming that the display was functional as described above at take-off, degradation to the point where the display is not useful would occur about once in every 10,000 missions. Note that the addition of a third, fully redundant, low voltage power supply would make this time interval nearly infinite.

3.4.4 Maintainability - The arc lamps in the illumination modules would require replacement every 1000 operating hours. Additionally, as described above, the display would require unscheduled maintenance every 1200 hours. Thus the overall Mean-Time-Between-Maintenance-Action is about 550 hours.

Given the early stage of the large area color display technology, a detailed maintenance and logistics plan for these displays has not been developed. However, the large size and weight of an 18 x 24 inch color projection display contraindicates removing the entire display from the aircraft for normal maintenance. Thus the aircraft and the display unit would have to be designed to allow virutally all maintenance actions to be performed with the display system in place.

The highly modular architecture of the large area color display lends itself to simplified logistics support. The display consists of only six basic replaceable module types. Maintenance would consist of the replacement of these modular items, as follows:

a) Projection Modules The projection modules, including the projection lens, beam-splitter, liquid crystal matrices, and mechanical mounts would be replaced as a unit with the display system in place on the aircraft. Access to the modules would presumably be by removing the diffusing screen from the front of the display through the cockpit. The modules would be pre-aligned during manufacture and contain provisions for automatic alignment on pins in the display system mounting frame. The replacement procedure would be to simply remove the old module, and insert the new module onto the alignment pins and tighten the mounting fasteners. The procedure could be accomplished without specialized tools.

The majority of the failures in the projection modules will be in the liquid crystal matrices. The modules could be repaired, by replacement of the liquid crystal matrices, at a depot facility with specialized alignment equipment.

b) Arc Lamps - The periodic replacement of the arc lamps will be the primary form of maintenance performed on the large area color projection display. Access to the lamps would be through access doors on the aircraft in front of the cockpit. The lamps would be pre-aligned and mounted on heat sinks which, like the projection modules, fit over alignment pins in the display structure. The frequency of lamp replacement seems to indicate that the lamps should be aligned on the heat sinks when purchased or that the alignment equipment be provided at an intermediate level.

c) Ignitors - The ignitor modules will be replaced at 8000 hour intervals and will also occasionally require unscheduled replacement while replacing the arc lamps. The modules would be accessed in the same manner as the lamps, and replacement of the ignitors should not require tools. The ignitor modules are encapsulated and are not repairable.

d) Low Voltage Power Supplies (2 Types) - The low voltage power supply modules for the arc lamps and for the interface circuitry will be located at the rear of the display unit and accessed in the same manner as the lamps. Replacement of these plug-in modules should not require tools. These modules may be repaired at a depot if desired.

e) Interface Circuitry Modules - The interface circuitry modules would not require frequent replacement. The method of mounting these modules is not fully clear, but access would be either through the front panel or through the access doors used to replace the lamps. The modules would simply plug-in and would probably not be repaired.

Figure 52 summarizes the estimated normal maintenance requirements of an 18 x 24 inch full color projection display. As the development of this technology continues, trade-offs between repairable/throw-away modules and depot/intermediate level repair facilities will be required.

3.4.5 Availability - The availability of the aircraft, based on the large format display system, as defined in DOD3235.1H Reliability Maintainability Handbook is:

$$\text{Availability} = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}}$$

where MTBF = Mean Time Between Failure

and MTTR = Mean Time To Repair

Module Type	Quantity Replaced	Per Module		
		MTBMA	MTTR	Cost
At 1,000 hr Intervals:				
Arc Lamp	8.00		0.3	400
Ignitor	0.50		0.5	500
Lamp LV Power Supply	0.15		0.5	1,500
Projection Module (Outside 9 Only)	0.09		1.0	6,000
Interface Circuit Module (Outside 9 Only)	0.05		1.0	800
Typical 1,000 hr Maintenance	9.00 Items	1,000	2.9	4,255
At 8,000 hr Intervals:				
Ignitor	8.00	8,000	0.5	500
Total 8,000 hr Maintenance	8.00	8,000	4.0	4,000
Unscheduled Maintenance:				
Interface Power Supply	1.00	6,700	1.0	5,000
Projection Module (Center 16 Only)	1.00	3,700	1.0	6,000
Interface Module (Center 16 Only)	1.00	20,800	1.0	300

Average maintenance requirements:

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Mean time between maintenance action = 550 hr
Mean time between unscheduled maintenance action = 1,200 hr
Mean time to repair (total) = 2.4 hr
Mean time to repair (unscheduled) = 1.0 hr
Average replacement parts cost/maintenance action = $4,500

Figure 52. 18 × 24 Inch Display Maintenance Requirements

For the DTACS large format display, the availability is 99.92%, based on the MTBF of 1212 hours and a MTTR of 1 hour, based on the data in Section 3.4.4.

3.4.6 Life Cycle Cost - The anticipated development costs of the DTACS display concept amount to $35M dollars, of which $18M is for software development and $17M is for hardware. Software development includes the necessary programming to develop the new formats for the display processors, the programming to perform the fusion of data and the control programming.

The recurring cost per shipset is estimated to be $500,000. This cost is comparable to recurring costs of present fighter instrument panels. Support costs for 10 year estimated life is $500,000 or $50,000 per year, which is slightly less than present fighter support costs.

4.0 SIMULATOR DEMONSTRATION REQUIREMENTS

4.1 VOICE RECOGNITION/RESPONSE

Voice recognition/response technology for the DTACS was reviewed. The voice response technology is in an advanced state of development with techniques ranging from low bit rate phonetic synthesis to high bit rate direct digital recording. The human voice covers a frequency range from 75 hertz on the low pitch end, for male speech, to greater than 10 KHz for some components of unvoiced speech in the phoneme(s). Acceptable speech quality is obtained over the telephone with a 3db band width covering 300 to 3000 hz.

The intelligence in human speech is conveyed by means of distinctive and transitioning sounds produced by the speaker. These utterances are called phonemes and the transitions are sometimes referred to as diphthongs or transemes. Speech can be synthesized with 50 to 60 phonemes. A normal speaking rate is on the order of 10 phonemes/sec. As an example, consider coding speech at one binary combination of 6 bits for each phoneme; i.e. 6 bits will provide coding for 64 phonemes. If these 6 bits are transmitted at 10 combinations per second then 60 bits/sec would be adequate for transmitting the speech. There are a number of voice synthesis techniques that try to model the human vocal track and achieve this low bit rate. Improvements are being made and it is expected that highly intelligible speech will be achieved by the low bit rate synthesis methods in the future.

At the other end of the technology spectrum, consider the direct digital recording of speech. Assume that a full 5 KHz band width is desired for the speech recording. Eight bits is adequate to quantize the speech amplitude (256 levels). Sampling the speech at the Nyquist rate, 2 times the highest frequency or 10 KHz, results in a bit rate of 8 x 10 KHz or 80,000 bits/sec. A typical word time in the English language is .5 sec. The phoneme synthesizer would require only 30 bits where the direct digital recording would require 40,000 bits to encode the same .5 second word. It is obvious from the economy of memory that the synthesis approach is the more desirable. However, for the DTACS simulation the direct digital recording was chosen because of its higher quality and the availability of large memory in most simulation computers. The voice synthesis technology will be further investigated, however, for the flight hardware in the 1990 time frame.

Voice recognition technology is not nearly as far advanced as voice response. As a result, the large market anticipated for speech recognition has not materialized. Current recognition schemes depend upon encoding, parameterizing and matching of the speech spectrum. This involves detecting the onset of voicing, time normalization, spectrum coding, extracting spectral features, and the storage and comparison of large amounts of digital data. At present speech recognition is at best a crude art. Recognition algorithms are improving in handling word boundaries, noise, amplitude and speaker variations, but 100% recognition scores under all conditions has yet to be realized. This realization will require the best of speech science, pattern recognition and artificial intelligence.

Current state-of-the-art in voice recognition may provide 100% recognition in a controlled laboratory environment, with a small vocabulary. During the DTACS study a number of speaker dependent commercially available "voice" recognition units were evaluated. One of the units was purchased and "trained" to recognize each word from the phrase "We were away a year ago". When each word is carefully spoken by the trained speaker into a properly positioned microphone, with a low background noise level, 100% recognition was achieved. When the same unit was input by a microphone, in an oxygen mask, placed in a flight simulator, and used with an increased vocabulary by an untrained speaker the recognition score drops significantly. 85% was measured under these conditions.

Available commercial recognizers all performed similarly in the flight simulator, without the mask. In a dome, reverberation is a problem. The acoustics of the dome surface are such that the voice sound pressure wave is reflected and returned to the source where it adds in level depending on the position and directivity of the microphone. The reflected wave, breath noise, and the sound simulation in the MACS dome degraded recognition performance. Performance can be improved by the following methods:

1) Training the voice unit in the noise environment in which it is to be used.
2) Making multiple training passes to capture the variety of ways a word may be spoken by the user.

3) Training the user to annunciate the words the same way each time.

4) Adjusting the input gain so as to improve the signal to noise ratio at the input to the recognition unit.

5) Use of a noise cancelling and directional microphone properly positioned with respect to the speaker.

6) Enabling the voice recognition unit with a push to talk switch.

All of the above methods should be applied in the DTACS simulation to enhance the viability of the voice channel as an input device. Further, the speech technology progress should be closely monitored during phase I efforts and alternative methods, best techniques, and future needs and trends evaluated through the DTACS simulation.

4.2 DIGITAL DATA DISTRIBUTION AND REALTIME I/O INTERFACE

The simulation of future fighter/attack aircraft requires an advanced crew station incorporating many pilot interactive control and display techniques new to avionics. These techniques are best implemented in the simulation environment by using many distributed intelligent peripherals all under control of a host processor. This concept has the advantage of being able to make full use of control and display techniques developed independently under various research and design projects. See Figure 53.

4.2.1 Host Processor - A precise specification for the host processor would require a major software effort to write a benchmark simulation and run tests on the host operating system overhead, Input/Output (I/O) throughput and Control Processing Unit (CPU) computational speed. The general requirements for a typical simulation of the type in question are well known. Therefore, the following system recommendation is based on past aircraft simulations of size and complexity similar to that expected with the integration of the DTACS crew station.

The host processor must be a high-speed digital computing system with an efficient real-time operating system. In addition it must have fast peripheral processor units to offload the CPU for I/O communication. It must have scientific computation capabilities and be capable of executing a high level scientific language, such as Fortran 77.

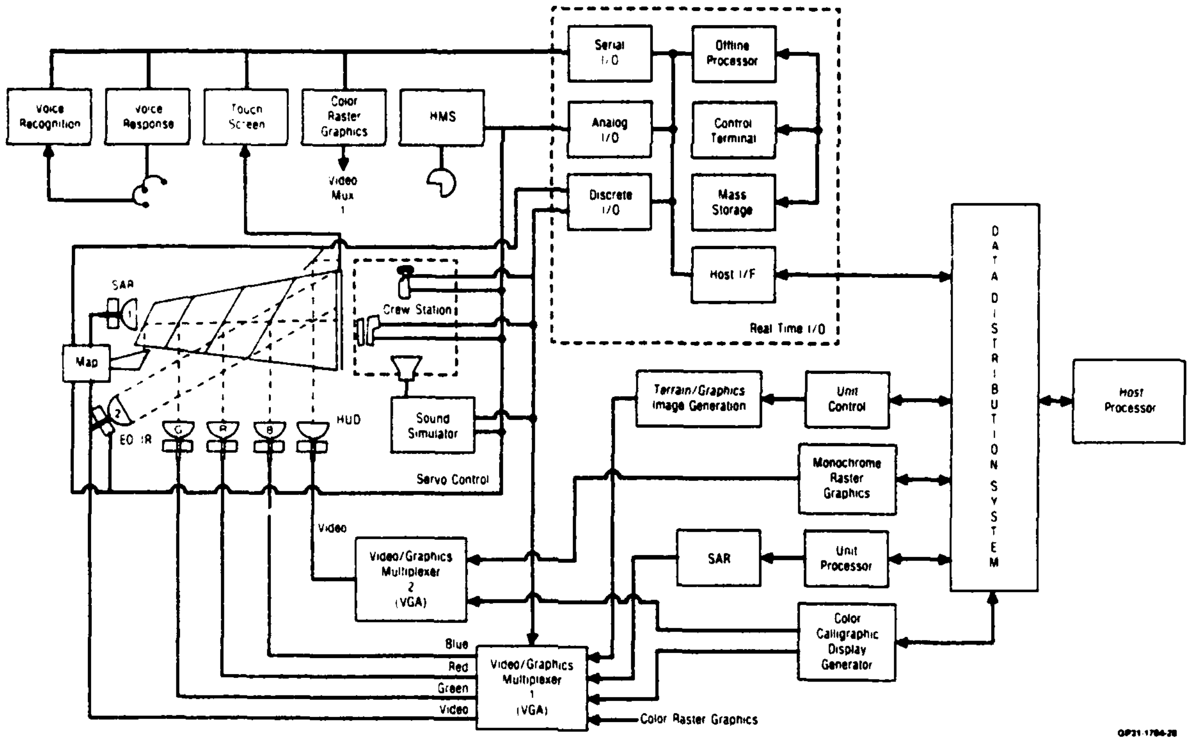

Figure 53. DTACS Block Diagram

The DTACS crew station should be integrated with a full mission simulator, including computer generated air-to-air threats, ground threats and terrain following/avoidance. This type of full mission environment will require a high computational speed which puts the host processor in the 5 MIPS (Millions of Instructions Per Second) class of computers. Other host processor requirements for this type of simulation include a minimum of:

1) 256K words of memory
2) Six peripheral processors and associated high speed data channels
3) One hard disk peripheral for rotating mass storage
4) One 1/2" high-density magnetic tape drive
5) One console display

For purposes of comparison note that the 256K words of memory refers to 256 (decimal) x 1024 60 bit words of memory.

The peripheral processor units are necessary to offload the CPU during data transfers to and from peripheral devices. There should be a minimum of six data channels, one for each peripheral processor unit. This includes three channels for data distribution (special purpose processor controller, slave controller, and graphics controller), and one channel each for hard disk, magnetic tape, and a network of console displays for software development. These high speed data channels must run with an I/O transfer rate of at least one 12-bit data word per microsecond on each channel and a full duplex I/O throughput of 500 words per real-time clock period.

4.2.2 Data Distribution

- o Data distribution is a system requirement that allows a single host processor to control several types of crew station subsystems.

Through data distribution one or more host processors may gain control of such devices as the color calligraphic display generator, Synthetic Aperture Radar (SAR) minicomputer, voice response/recognition, sound simulator and helmet mounted sight.

The host processor must set up high speed data transfers to be carried out by the peripheral processor units. These peripheral processor units must communicate at high speed but only for short distances and with a signal format unuseable by any normal crew station peripheral. Due to high throughput requirements of the peripheral processor's data channels, the largest separation recommended for a direct interface to the host processor is on the order of tens of feet. Therefore, the data distribution equipment must be physically located near the host processor and contain special signal conversion circuits to directly interface the high speed, short distance control and data from the peripheral processor units. The flexibility to accommodate a simulation environment with multiple crew stations is essential to the future growth of any new crew station. Therefore, the facilities logistics requires a larger separation of host processor and crew station. This separation distance is typically on the order of several hundreds of feet and data distribution must provide data buffering with long distance transmitter/receiver circuits and DMA (Direct Memory Access) transfer control.

To provide flexibility for incorporation of various crew station peripherals the DTACS data distribution system should be divided into three very similar but independent hardware units. Each unit represents a separate data link from the host processor with a dedicated peripheral processor and data channel cable. The following breakdown of these three units provides a recommended primary interface description for the DTACS data distribution.

1) Special Purpose Processor Controller
   - Minicomputer control for terrain radar map imagery and high resolution SAR video.

2) Slave Controller
   - Terrain map (high quality terrain video)
   - Sensor map (high quality FLIR video)
   - Computer generated imagery (high resolution, high speed color computer graphics)
   - Real time I/O (voice response/recognition, touch screen, color raster graphics, video disk, helmet mounted sight, Horizontal Situational Display (HSD) moving map servos, sound simulator, cockpit switches and controls)

3) Graphics Controller
   - Monochrome raster graphics (Head Up Display (HUD) highway in the sky)
   - Color calligraphics (for normal HUD graphics, HSD graphics, main Red, Green, Blue (RGB) projector graphics and air-to-air radar video)

The special purpose processor controller should provide the host processor control of high speed intelligent peripherals. An example of this is the radar map which requires high speed data transfer with minicomputer control of a camera mounted on a translator for normal radar imagery or high resolution SAR imagery stored on hard disk.

The slave controller should control slave devices in a slave interface chassis and microprocessor based intelligent peripherals connected to the real time I/O. The slave interface chassis are distributed throughout the flight simulation facility and can be located wherever the simulation equipment is constructed. For example the slave controller for the terrain and sensor maps must be located near them and is used to drive the camera/translator system to get terrain and FLIR video. Typically unit controllers provide large groups of slave D/A (Digital to Analog) converters, A/D (Analog to Digital) converters, DOs (Discrete Outputs), and DIs (Discrete Inputs). The real time I/O should be also controlled through the slave controller but will be described in a subsequent section. Computer generated imagery must also be controlled through the slave controller and can provide a high resolution graphics alternative to the terrain and sensor maps.

The graphics controller should control high speed color raster and calligraphic or stroke written graphics systems. The large volume of data transferred to this type of peripheral has necessitated their placement on a separate data channel. It is recommended that each high speed calligraphic system generate up to 8 medium complexity displays to accommodate the current displays planned for the DTACS crew station.

To make use of all the various types of display imagery, two video/ graphics multiplexers are recommended. One multiplexer should provide color imagery in the crew station from four sources, one of which is the color calligraphic display generator controlled by the graphics controller. The other sources include SAR video controlled by the special purpose processor controller, terrain/sensor map video controlled by the slave controller and color raster graphics controlled by the slave controller through real time I/O.

The second video/graphics multiplexer should provide monochrome video to the HUD. This multiplexer has two sources of imagery. One source is a monochrome raster graphics display system controlled by the graphics controller. It is an intelligent system with automatic hidden line and surface generation capability. The second source is a monochrome output of the color graphics display generator which provides the normal point-to-point line drawing capability required by a typical HUD.

4.2.3 Real Time I/O - Reliable system architecture requires an interface subsystem in close proximity to the crewstation. The recommended interface subsystem, real time I/O, must provide the means to link the DTACS crew station, host processor and the simulation operator. For flexibility and low cost it should be a microprocessor controlled interface with separate component boards for the CPU, mass storage interface, host interface, analog I/O, discrete I/O and serial I/O.

Hardware for the DTACS real time I/O may be a mixture of specially designed, previously designed and commercially available equipment. Communication may be initiated by either an interrupt request or a polled operation. The allocation of interrupt priority or polling sequence should be under software control. The component systems should meet the following requirements.

Central Processing Unit (CPU)

The real time I/O should be under the control of a microprocessor based CPU. The CPU board must perform the master role over the slave interface boards residing in the real time I/O. The CPU should be a sixteen bit microprocessor, structured over a three bus communication network. The interface slaves should be addressed through a global bus which will serve the main communication link throughout the real time I/O. An on-board local bus will be utilized by the CPU to communicate with the on-board Random Access Memory (RAM), Electrically Programmable Read Only Memory (EPROM), interrupt controller, serial I/O port and parallel I/O ports. The third bus will be an off-board local bus which the CPU will control. It will be utilized to communicate with intelligent peripheral boards whose function is dedicated to CPU usage, such as the mass storage interface. The real time I/O will be capable of operation in an on-line mode with the data distribution system in an off-line mode with the CPU providing complete system control. In order to provide the off-line capability, the CPU board will contain a minimum of 32K words of RAM space. The operating system software will be contained in the on-board EPROM.

Control Terminal

The real time I/O should contain a user control terminal for operator interface to the simulation computer system. The control terminal can communicate with the CPU board through an RS-232C serial port. The terminal should be comprised of a commercially available computer terminal with a touch sensitive overlay on the cathode ray tube. Operator actions can be enterable through the keyboard and the touch screen. The terminal should be capable of transmitting and receiving data at selectable baud rates from 110 to 9,600 baud. Communication between the CPU and the control terminal can be initialized by fulfilling the full RS-232C handshake requirements.

Mass Storage

The central processing board of the real time I/O must be interfaced to a mass storage control board. The mass storage can provide the capability of controlling both flexible disk and winchester hard disk storage devices. Control of the operation of the mass storage board should be performed by an on-board I/O processor with all operations occurring in byte format. The board should communicate with the CPU board through the CPU's off-board local bus. Data transfers between the CPU and mass storage boards should utilize Direct Memory Access (DMA) operations. Prioritization of DMA channels should be accomplished by the I/O processor and a DMA controller. The record files for the storage devices must be programmable with minimum selections of 128, 256, 512 and 1024 bytes per sector. Finally each device controller should be capable of driving up to four storage disks.

Host Interface

The host interface board must provide the communications link between the Real Time I/O and the data distribution system. The host interface must accept commands for read and write cycles from the data distribution system and gain control of the real time I/O global bus for the appropriate commanded usage. The interface will then support block transmissions of data to or from the real time I/O. These transmissions can be sustained in a pipeline mode of operation.

Analog Input/Output

Analog Input

The analog input unit must be capable of accepting an analog signal and converting it to a digital representation of the signal. The board should contain the input channels and memory allocation for storage of the input values until the value is requested by the CPU. When an input is received, it should be converted by an Analog-to-Digital Converter (ADC) into digital format. The data can then be loaded into a Digital-to-Analog Converter (DAC) for reconversion to an analog format. The new analog representation can then be compared to the original analog input value and any errors can be corrected. The corrected data should then be stored in memory for usage by the CPU. An analog input microprocessor can provide the sequential sampling control of all input channels.

Analog Output

Analog outputs should be microprocessor controlled, to convert digital data into an analog signal for output. When new data is available, the analog output microprocessor should interpret a command byte to determine how to individually step the dig'tal data through the proper DAC output channel. The DAC output should then be wrapped around into an ADC and reconverted into digital data. The reconstructed digital data should be stored in memory for usage by the CPU in comparing digital data versus analog output values. The analog output will respond to the CPU on an interrupt generated when the first word of data is written into the analog output RAM. Once an interrupt is generated, the analog output should ignore any further addressing by the CPU until the interrupt is cleared.

Discrete Input/Output

Discrete I/O words should contain twelve bits of data resolution. A channel can be individually selected at a patch panel. When a channel is in the output mode, a wrap around check should be made on the data placed on the channel. The wrap around check must be commandable for either a single channel or all channels through a command word bit.

Serial Input/Output

A serial I/O is required to provide a network of serial ports with the capability of generating multiple protocall schemes. The unit should interface with the CPU through RAM. The unit will be capable of slow to high speed serial communication in asynchronous or synchronous operations. The serial I/O must be designed to the following requirements:

1) CPU Control - The interface must be controlled through an on-board microprocessor. This processor should provide an 8-bit structure for interface compatibility to the on-board memory and serial interface circuits. The CPU software must provide for programming of each serial port's functionality,

interaction with the real time I/O CPU, smoothing or reformatting of serial I/O structure for compatibility to the real time I/O and peripheral devices and for local bus master operation. The CPU can be a RAM based structure with the serial control module routines stored in EPROM.

2) Random Access Memory - The unit should contain a 2K x 8 RAM space. The data space should be allocated as 1K for inputs and 1K for outputs. The memory will be implemented in a dual port scheme with interleaved operation between the real time I/O CPU and on-board utilization. Access time from the serial controllers should be less than 8 microseconds, while access will be less than 200 nanoseconds from the global bus. There should also be a 256 x 8 scratchpad RAM for CPU calculations.

3) Serial Ports - The unit should contain a minimum of six (6) RS-232C/RS-422 ports, two (2) RS-232/422/PN1360 ports and growth provisions for an Ethernet port. The RS-232C/RS-422 ports must contain a set of line drivers and receivers for each standard interface channel which should be jumper selectable between the desired standard. The RS-232C should have baud rates from 110 to 19,200, while the RS-422 should have baud rates of 9,600 to 1 megabaud. The RS-232/422/PN1360 ports should have baud rate selections of 9,600 to 1 megabaud, with jumper selection between line drivers and receivers. The RS-232/422/PN1360 ports should be capable of a jumper selectable DMA interface to the dual port RAM. All ports should be capable of providing an asynchronous or synchronous interface to peripheral devices.

The six RS232/422 ports should be utilized for control parameter transmissions, while the RS-232/422/PN1360 ports can perform medium to high speed data transmissions.

4.3 COMPUTER(S)/SOFTWARE

4.3.1 DTACS Software Requirements - Software requirements for the DTACS simulation include a basic aircraft model, conventional avionics systems and sensors, plus new concepts in cockpit controls and displays. This software must include not only the system modeling, but also the interface programs for driving the simulator hardware.

4.3.2 Aircraft Model - The aircraft model must be a six degree-of-freedom model, with the size and weight of a fighter/attack aircraft. The model should handle either a full-up, handling qualities version, or a reduced-core equivalent systems model. The full-scale handling qualities model could be utilized for specific tasks such as takeoff and landing, with real-time switching to an equivalent systems model for most of the airborne mission tasks. Over most of the mission profile, the equivalent systems model would be more than sufficient aerodynamically and most cost-efficient; however, the handling qualities model provides more realism for certain maneuvers and requires only about 20K extra core during those times.

Either model will require the inclusion of several similar software modules. These modules are identified at a high level in the flow diagram in Figure 54. The analog and discrete signals from stick, throttle, gear and speedbrake are converted to digital. The primary flight controls have alternate inputs from pilot relief modes (attitude and altitude hold) or from a maneuvering attack system like MAS or IFFC. The attitude of the control surfaces then feeds into a drag model, along with the fuel and stores configuration on board the aircraft. The results of the drag and thrust calculations go into the equations of motion, which feed the NAV (Navigation) module. An addition to a conventional aircraft model is the TF/TA (Terrain following/Terrain Avoidance) model, which generates steering commands either for an auto or a manual mode, and a highway-in-the-sky display for the HUD (Heads-Up Display). TF/TA requires the availability of terrain and threat data, plus weather information. A simplified TF/TA model might be employed, with preplanned mission profiles and target/threat placement. A full scale TF/TA simulation would require approximately 250K core to execute. This means that such a large program would have to be run in another processor, with the accompanying I/O and timing considerations. Since the primary focus of this demonstrator should be on the evaluation of new control and display techniques, it would be more cost-effective to employ the simplified TF/TA system with the preplanned profiles.

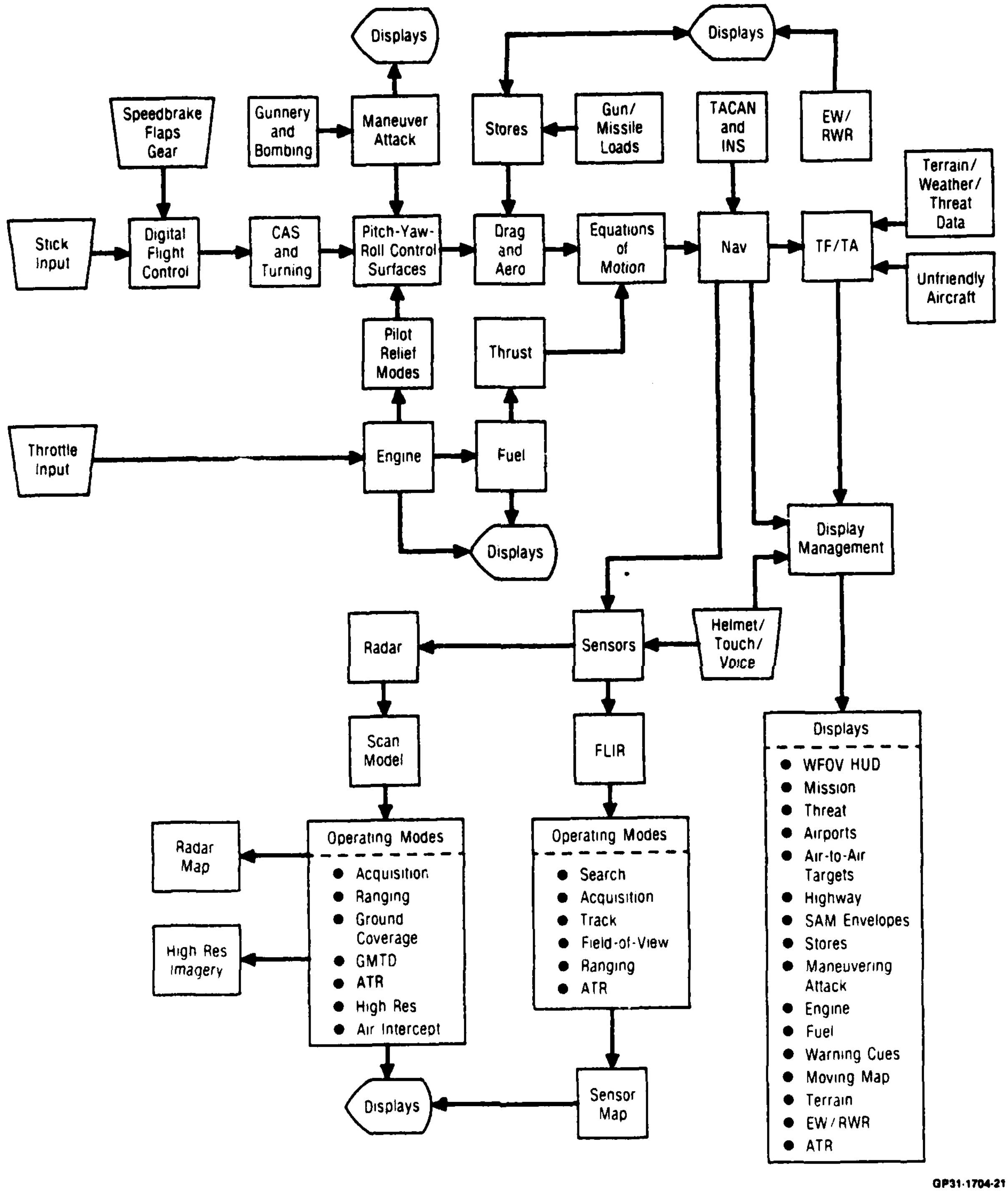

Figure 54. DTACS Software Flows

4.3.3 Sensor Models - The sensor models must include basic radar and FLIR operations. The radar model should consist of:

1) Scan mode
2) Real Beam Ground Map
3) Doppler Beam Sharpening
4) SAR (Synthetic Aperture Radar)
5) Ground Moving Target Detection
6) Precision Velocity Update
7) Air-to-Surface Ranging
8) Precision Target Track
9) High Resolution SAR
10) Auto Target Recognizer

With the exception of the high resolution SAR imagery, the other modes can be provided from a radar map with 10-foot resolution. The high resolution SAR images would come from specially processed radar video stored on disk. The digital commands from the radar simulation could then be converted to analog signals to drive a radar map so the appropriate ground patch should be displayed.

The Electro-optical/Infrared (EO/IR) simulation must include basic modes such as search and track, wide and narrow fields-of-view and boresight correlator. Additionally, an auto target recognizer (ATR) model should be required.

4.3.4 Cockpit Controls - The DTACS cockpit should be controllable by four basic input sources:

1) Stick and throttle
2) Voice recognition/response
3) Touch panel
4) Helmet Mounted Display/Sight (HMD/S)

The stick and throttle are the inputs for engine and primary flight control, but should also be used in conjunction with voice control during high-g maneuvers (when the pilot cannot lean forward to use the touch panel). HOTAS concepts should be included.

Speech recognition and response should also be utilized as control techniques. Present state-of-the-art for a speech vocabulary size is 100 words, but multiple vocabularies can be used for different aircraft modes if interactive loading of vocabularies is used. For example, one vocabulary may be loaded for air-to-air flight and another automatically loaded in when the pilot selects air-to-ground mode. To communicate with the host computer, a simple encoding scheme (e.g., one number identifying the word or phrase spoken) should be utilized. The voice commands should have the same effect in terms of control as pushing a button in a conventional cockpit. Voice response, on the other hand, should be used primarily to provide feedback to the pilot on operations performed (e.g., "COMM 1 SELECTED"), or to provide automatic warning cues (e.g., "GENERATOR FAILURE"). Predetermined messages can be recorded and be provided to the pilot upon occurrence of certain actions or emergency conditions.

Software interface for touch panel control can be relatively simple: the software only needs to see an X,Y position input where the touchscreen is being activated. It should be necessary, however, to provide integration of the touchpanel signals with the voice control and display management modules. Then, if the pilot tries to move a stores display over radar video, the display management model should have to either clip the stores display or prevent it from following the X, Y position of the pilot's finger.

Control of a Helmet Mounted Display/Sight (HMD/S), from a hardware interface viewpoint, is also relatively simple. The analog signals from the helmet providing X, Y, Z position and pitch-roll-yaw orientation can be converted to digital inputs in the simulation. When the pilot is looking at the DTACS display, he should have a cursor display which is controlled by where he is looking. Provisions must be made in the software, then, for cursor functions. For instance, if the pilot points the cursor at a target on a radar display and depresses the Target Designator Control (TDC), that target can be designated.

4.3.5 Display Management - Control of the cockpit displays encompasses two primary tasks: control of the large tactical situation (or moving map) display and segmentation of the other smaller displays. The moving map display can be provided by a 35-mm filmstrip projected onto the rear projection screen. Map drives in

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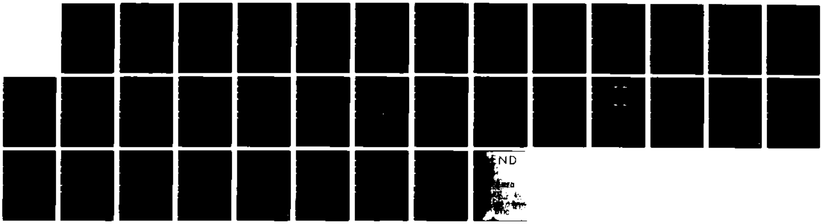

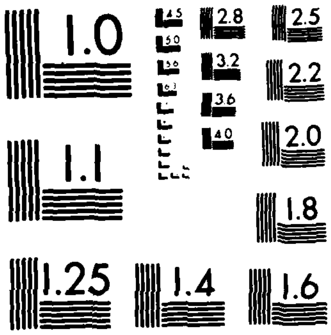

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

themselves should be fairly simple: position along the filmstrip, position across the width of the filmstrip and rotation. Included with the moving map logic, however, must be control of the level of fusion desired; i.e., overlaid on the map, is it desired to show weather data only, or weather data plus airport data, or threat and target data, etc.. Additional possibilities are to show the areas of sensor coverage or to show mission data.

Software controlling the segmentation of the smaller displays covers several areas of consideration. First is positioning of displays on the big screen, since the pilot will be able to move displays about the screen. Closely related to display position is the capability to blank the map display where another display is presented, and limiting or clipping of displays to prevent them from going off the screen or overwriting other displays. To reduce clutter and redundancy of information to the pilot, there should be no repeater displays. Logic for the appearance of automatic warnings or emergency displays is required, as well as some logic for control of the display generation and video multiplexing equipment.

4.3.6 Hardware Interface - Extensive hardware interfacing is required, much of which has already been identified above. The analog-to-digital and digital-to-analog conversions for voice, helmet and touch control and for stick and throttle switchology, already have been discussed. The graphics interface involves three general areas: calligraphic outputs for providing alphanumerics and other stroke symbology, fairly static pictorial displays such as an armament display, and the capability to generate dynamic displays such as highway-in-the-sky in real time. Generation of the highway will require either extensive hidden surface calculations within the host computer, or a graphics generator which can handle hidden surface algorithms.

Further hardware interface requirements include map drive signals for a terrain source, a radar source, an EO/IR display source and the moving map projection. Sound simulation of aircraft engine, gun and missile launch noises is desirable. Finally, some interfacing with the optics package is required, including display positioning, video blanking, interrupt control and video multiplexer control.

4.3.7 Computer Requirements - An estimate of the core requirements for the DTACS software modules is presented in Figure 55. Note that this estimate is based on an equivalent systems aircraft model and simplified TF/TA, and assumes that all

Program	Core Requirement (Octal)
Executives, I/O, Common Arrays	63000
Basic Aircraft	100000
Target/Threat	7000
Displays (Conventional)	16000
Displays (Pictorial)	6000
Display Management	5000
Radar	10000
EO/IR	2000
Stores	2000
NAV	2000
Helmet	4000
TF/TA (simplified)	3000
Crew Station (stick & throttle, lights, sound)	4000
Terrain data and control	3000
Air-to-air target projection	4000
Equations of motion	2000
Auto target recognition	3000
Maneuvering attack	15000
Moving map	2000
High resolution SAR	1000
Highway In The Sky	3000
Voice, touch interface	2000
Miscellaneous	5000
TOTAL	320000

Figure 55. Core Estimate for DTACS

programs will be loaded simultaneously. With total core requirements of 320K, this simulation can be run on a large mainframe, or on multiple microprocessors. In addition, some offline processors will be required for control of certain systems components like the radar map, voice recognition/response, some graphics applications (highway-in-the-sky) or for full-scale TF/TA algorithms. A suggested processor configuration is shown in Figure 56.

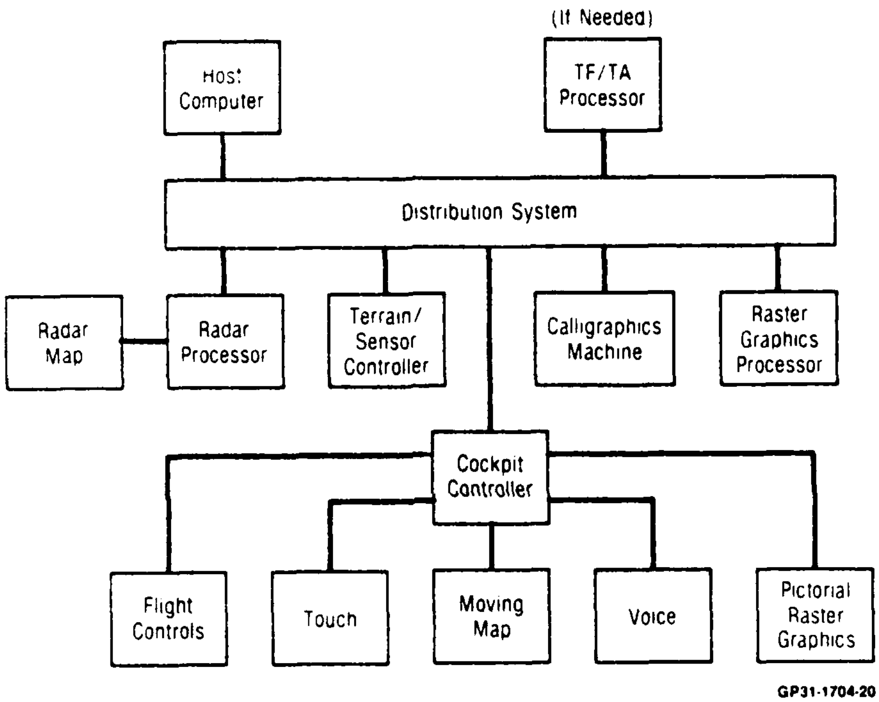

Figure 56. DTACS Processor Configuration

4.3.8 Risk Assessment - The technological risk in this program from a software point of view is low, for both the simulator demonstration and the onboard aircraft application. In conjunction with TF/TA, generation of hidden surface displays could also be a problem area, since the core requirements for having this problem reside in the host computer also would be very high. The remaining portions of the program - aircraft, avionics and sensor models, plus hardware interfaces - should be readily implemented on present-day computer systems.

4.4 VIDEO-GRAPHICS MULTIPLEXER (VGM)

The VGM receives video and stroke written calligraphic signals as inputs and time multiplexes them. The VGM outputs are X and Y drive signals to the display deflection circuits and Red, Green and Blue intensity signals to the displays Z axes. Interrupt signals are also sent back to the graphics generator. The interrupts cause the graphics generator to start/stop sending data.

Color information from the high speed graphics generator is decoded at the VGM to extract red, green and blue graphics signals from the Z (intensity) output, see Figure 57.

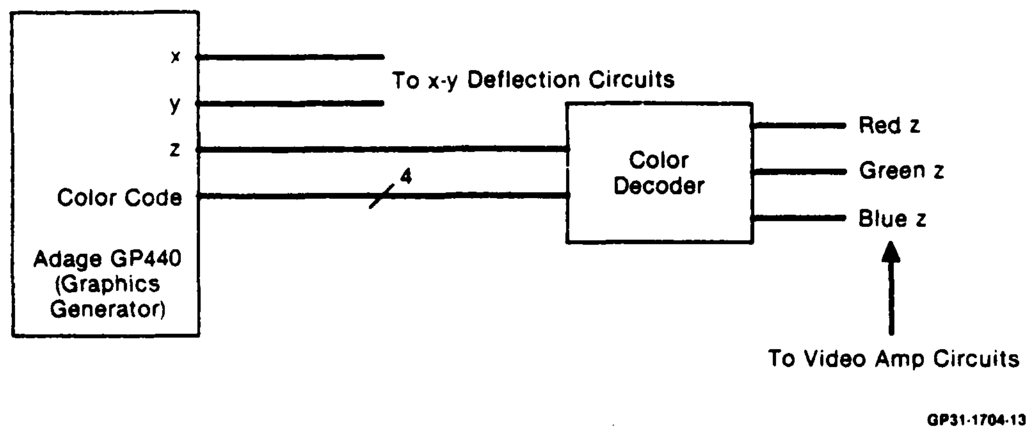

Figure 57. Adage Color Graphics System

The red, green and blue video outputs are applied to the red, green and blue CRTs which are then combined optically to produce the projected color cockpit display.

The primary usage for the DTACS project is mixing of terrain map video (or other TV data) and the stroke written graphics from a high speed graphics generator.

4.4.1 Video Receivers - A modular packaging design is best for a variety of receiver circuits. The graphics video should be received differentially, with dc offset and gain controlled prior to application to the switching circuits. The TV video, derived from several sources, should also be received differentially and similarly conditioned prior to switching. A third video input is available for a second TV video, radar video, etc.

4.4.2 X-Y Receivers - The graphics X-Y deflection signals should be received differentially, conditioned and sent to the X-Y switching circuits, see Figures 58 and 59. The TV sweeps are generated in special circuits which accept horizontal and vertical drive inputs from the sync and drive generator. The sweep rates required are from 5 KHz to 30 KHz (horizontal) and from 32 Hz to 95 Hz (vertical). Variable rate ramp generators are required for rapid switching between the various signal sources: Standard 525 line (RS170), and the NEC Advanced Personal Computer and 1000 line (RS343) TV generators. The VGM Sweep circuits should have as an added feature the capability to change raster amplitude and location using internal or external quasi-DC input.

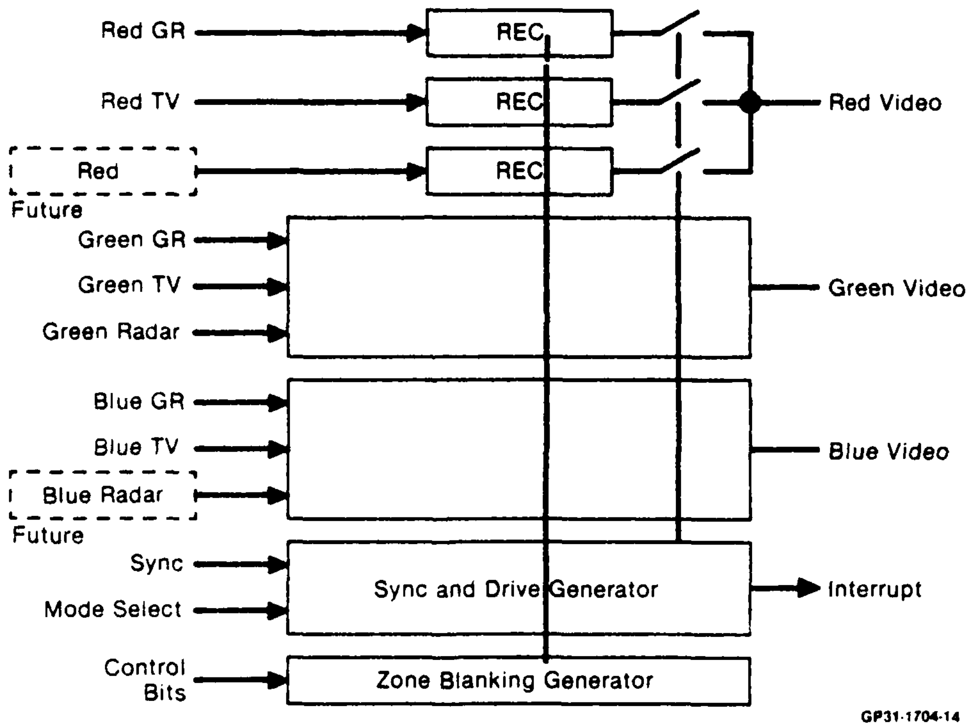

Figure 58. Video Graphics Multiplexer

4.4.3 Sync and Drive Generator - The sync and drive generator must receive composite sync and phase lock to the horizontal signal, within a 1/2 line period. External mode select signals determine one of seven modes:

1) Graphics
2) TV_1
3) TV_2
4) TV_1 + Graphics
5) TV_2 + Graphics
6) $TV_1 + TV_2$
7) $TV_1 + TV_2$ + Graphics

The interrupt can be derived from the TV vertical drive signal. The interrupt must be timed so that the graphics generator begins its output at a time dependent on the desired output display format.

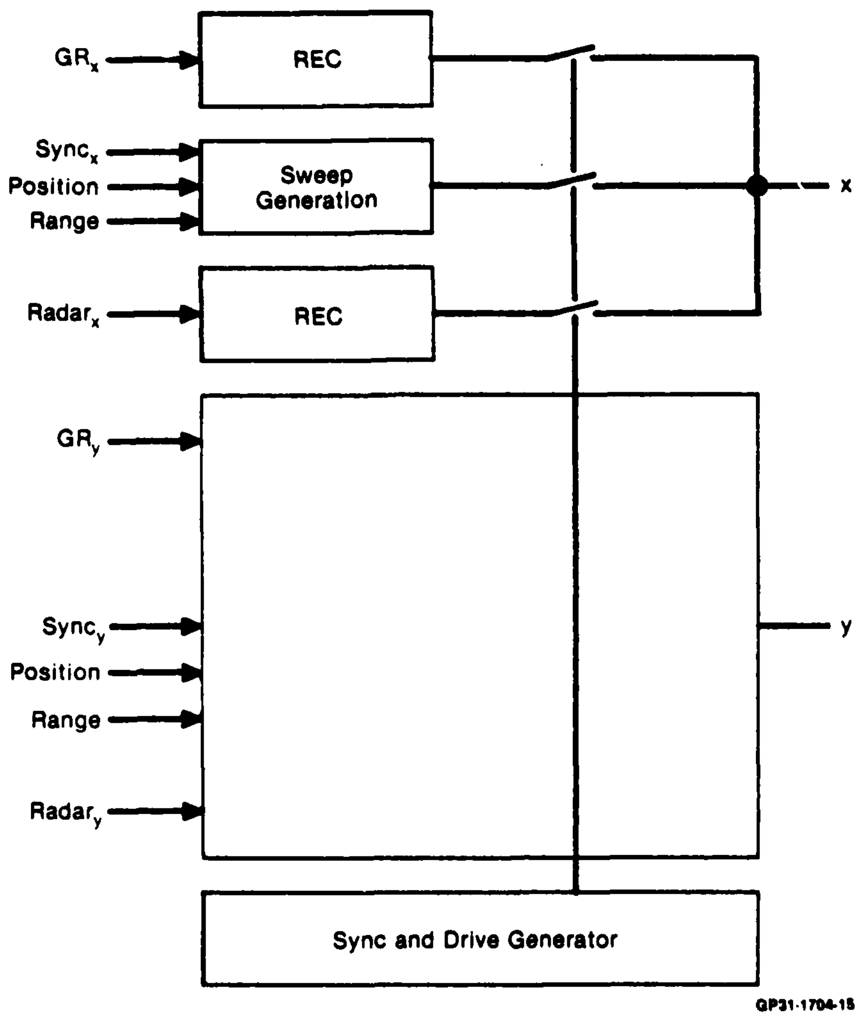

Figure 59. (Continued) Video Graphics Multiplexer

4.4.4 Zone Blanking Generator

A zone blanking generator provides the required blanking, in preselected areas of the screen to enhance the graphics display contrast. The generator receives digital information for dynamic blanking selection.

4.4.5 VGM Switching System

The multiplexer switching should be accomplished with solid state FET switches. The FETs must be carefully chosen to insure low cross-talk and feedthrough.

4.5 OPTICAL DESIGN

The majority of the optical design is directed towards the head-down displays. However, the most visible optical components are the wide angle HUD beam splitter/mirror assembly. See Figure 59.

4.5.1 Head-Up Display - The wide angle HUD should be centered at (-)4° relative to the design eye position allowing a 20° vertical by 30° horizontal instantaneous/total field of view. The HUD should be focused at 20 feet to be compatible with a 40 foot diameter simulator dome and to minimize parallax and distortion. Angular accuracies should approximate existing production flight models: 0° to 10° field, 1-2 milliradians (mr); 10° to 20° field, 2-4 mr; 20° to 30° field, 3-6 mr. Mounting must be designed to minimize visual obstructions. Background brightness will probably be reduced 20% due to transmission losses through the coated optical surfaces. The greenish hued HUD image should have a resulting brightness level of 2-3 foot Lamberts.

The wide angle HUD imagery must originate from a CRT coated with P-43 phosphor having its spectral peak at 550 nanometers. The tubes operational brightness level will have to be around 10,000 ft. Lamberts.

A 152 mm f/1.9 lens will be required to project the image onto a curved rear projection screen at 2.4 x magnification. The screen will require a gain of 5 coating to increase the image brightness and a computer selected 21 inch radius of curvature to minimize parallax and distortion, when focussed for use in a 40 foot diameter dome. The lens can project the CRT image up and across the air space behind the touch screen (see Figure 60)

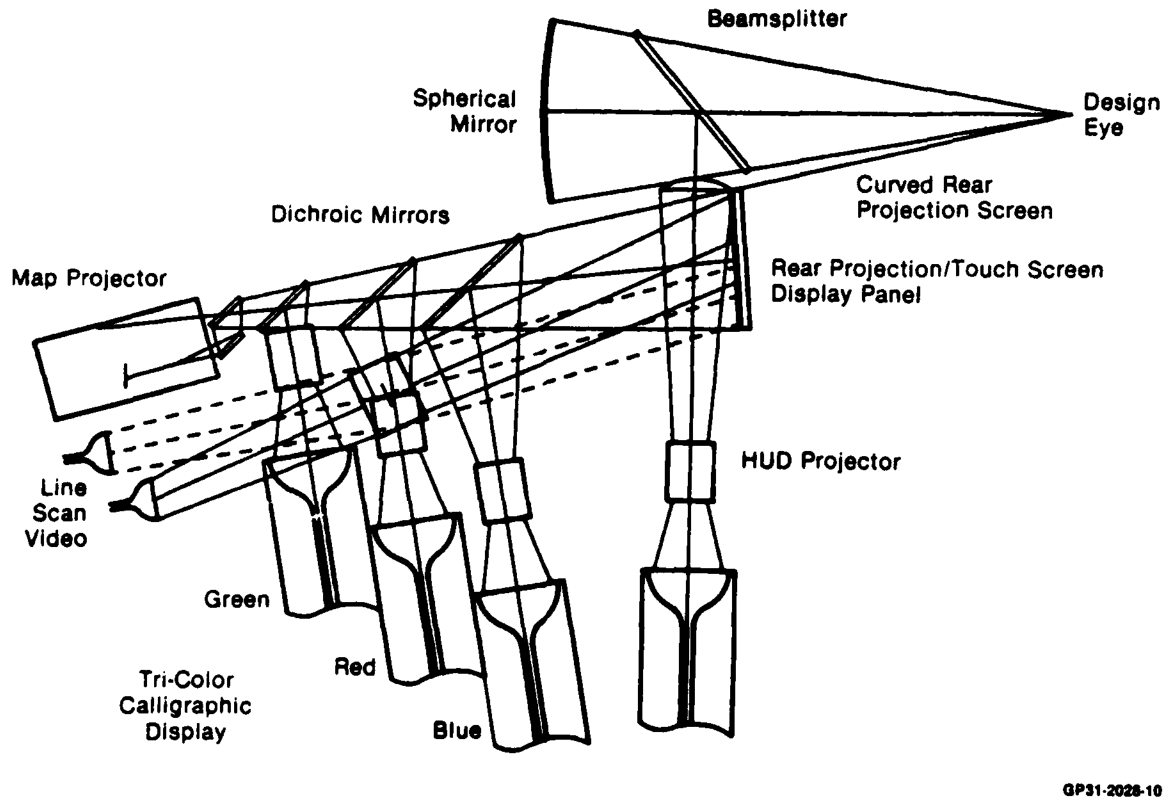

Figure 60. DTAC˷ jection System

The projected brightness level reaching the pilot is calculated from:

$$E = 5[2TB(1-\cos\theta)/M^2]$$

where, θ = 1/2 angle of the lens rear clear aperture from the CRT

T = lens transmission

B = source brightness

M = magnification (at screen)

and is further reduced by reflections from the beamsplitter/mirror assembly.

The 36 inch radius HUD mirror should have an additional 10% reflective coating peaked for 550nm. applied to its working surface. High efficiency anti-reflective coatings must be applied to the back surfaces of this assembly to reduce secondary reflections to a fraction of the original (.25% - 2.5%).

4.5.2 Display Panel - The display panel will be located below the wide angle HUD. It may be a rear projection screen having a high gain coated surface on one side and a Fresnel lens textured surface on the other. The screen must be touch sensitive across its entire viewing area. Rear projections from the RGB calligraphic projectors, EO/IR, SAR or the moving map display must be seen unobstructed either singularly or with all displays combined.

The panel should be a 16 x 21 inch section cut from a Fresnel lens having a focal length of 54 inches. The section must be cut such that the lens center will bisect the panel's top edge and direct the off-axis light rays towards the Design Eye position (Figure 61). A fine pitch (groove spacing) of the lens is required, so as to not limit resolution.

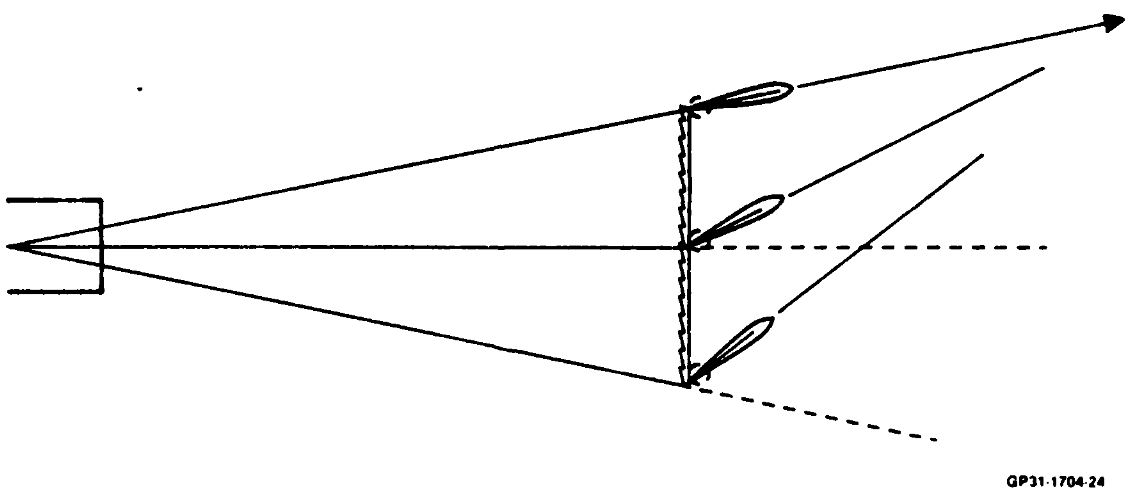

Figure 61. Fresnel/High Gain Per Projection Screen

The backside of the lens should contain a 5 gain rear projection screen coating, increasing the level of energy 5 times by changing its distribution pattern from a spherical shaped lobe to a narrow directional pattern as seen below.

One-half inch borders will be required to contain the touch panel electronics reducing the screens viewing area to 15 x 20 inches.

4.5.3 RGB Calligraphic Display - The RGB calligraphics are to be projected on the display panel through three separate projection systems. These displays can indicate to the pilot basic flight, engine and weapons status, in 3 primary colors and combinations of those colors and a combined "white" light display. Software generated symbology designed to work with the touch panel system can be displayed anywhere in the viewing area.

The calligraphic display should use phosphors selected for RGB color emissions. P56, P53 and P22 (pale blue silicate) are recommended respectively. Each tube's display should be reimaged at 5X magnification onto the display panel. A high quality, fast, six inch focal length lens will be required for the projection lens. The projected image must be reflected from a dichoric beamsplitter which has been selected to work with the individual color tube. Figures 62, 63 and 64 each represent the spectral characteristics of a red, green or blue color projector. They contain plots of the tubes spectral emissions and the dichroic reflective color distribution on a photopic background curve, representing the eye's response. All curves were used to determine color quality and brightness levels reaching the pilot. Four (4) foot Lamberts can be predicted for the blue and a minimum of 6 foot Lamberts are predicted for both the red and green. Resolution will probably be limited to a 20 mil spot (the magnified image of the CRT scan spot).

4.5.4 EO/IR, SAR, etc., Displays - Two line scan video displays must be available for projection onto the display panel. The image should be fixed in size and displayed along the sides of the panel. One of the displays must be capable of vertical movement, controlled by the pilot.

These displays can originate from high brightness, 9 inch diagonal CCTV's. 525 line video units containing P-4 phosphor can reproduce the black and white imagery. They should be re-imaged at reduced magnification (83%) on the display panel by two fast, long focal length lenses. One lens can be located near a pivot point allowing the vertical movement of the image along one side of the viewing area. The display unit must also be displaced to maintain a common axis with the lens. The tubes can have fixed tilt with respect to the axis maintaining focus across the image. Up to 50% keystone correction will be required. The minimum display brightness required is 2 ft. Lamberts. A design goal of 3-4 ft. Lamberts is believed reasonable.

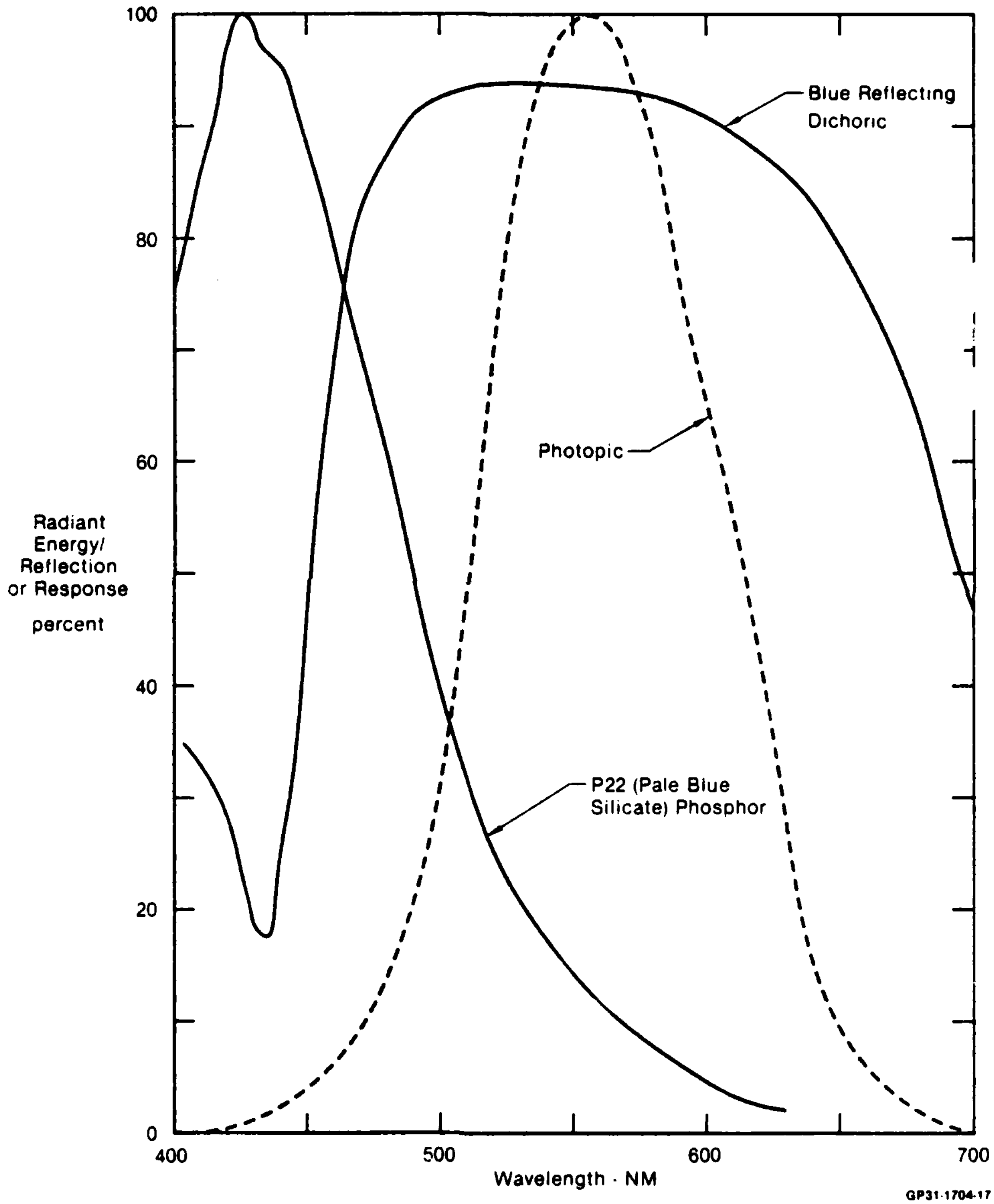

Figure 62. Blue Calligraphic Projection System

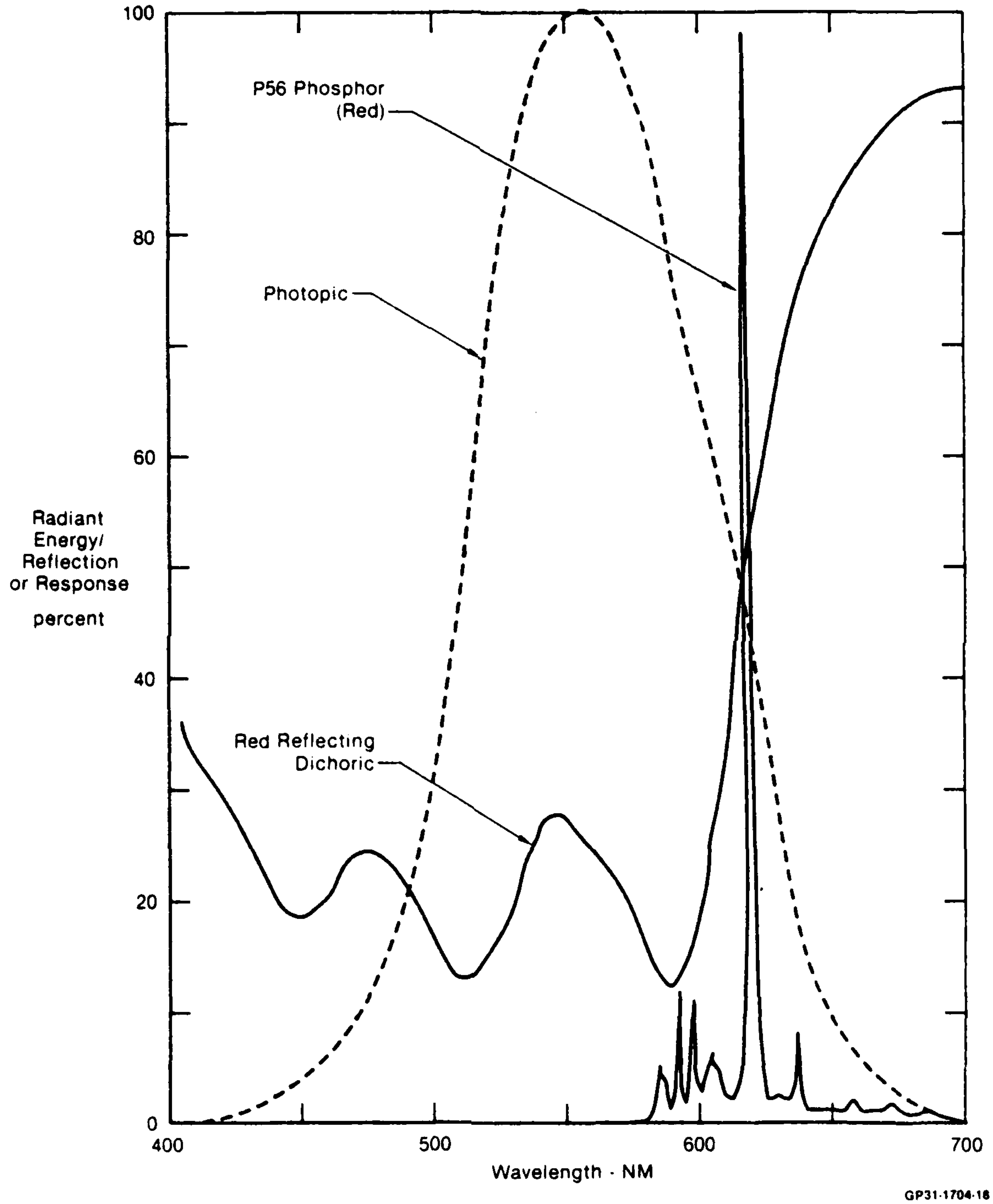

Figure 63. Red Calligraphic Projection System

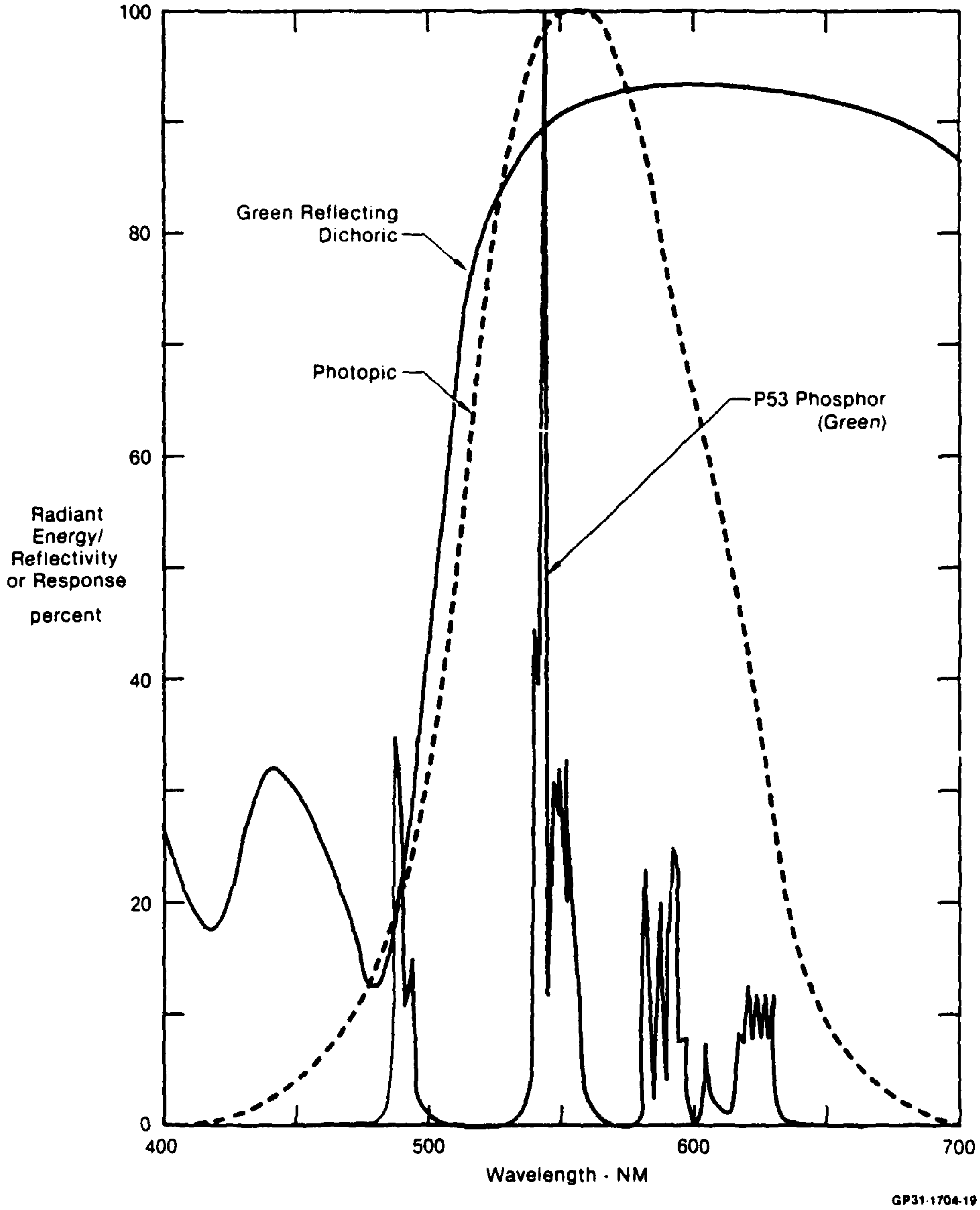

Figure 64. Green Calligraphic Projection System

4.5.5 Moving Map Display - The map display should fill the entire 15 x 20 inch viewing area with imagery originating from the color 35mm film strip. Brightness levels in excess of 2 ft. Lamberts should be possible. This background projection can consist of a wide variety of subjects that can be retained on film. High speed search, rotation and variable speed translation of the display corresponding with flight direction and speed will be possible. Background imagery can also be used with superimposed images from the RGB Calligraphic, EO/IR and/or SAR displays.

The full color map display when projected through the backside of the RGB dichroics will have the greatest percentage of usable light reflected. However, the (transmittive) inefficiencies of the dichroics will allow illumination from the map display to be seen on the display panel.

For the future, CGI could be added to the background display, using high brightness, color video projection equipment.

4.6 COCKPIT MECHANICAL ARRANGEMENT

4.6.1 Cockpit Design - The cockpit should be designed to house the visual, aural and tactile advanced concepts for simulation demonstration. The cockpit design must include Hands On Throttle And Stick (HOTAS) controls. The design must permit the cockpit to also be used with out-the-window visual systems.

The cockpit should be designed in two sections for ease of maintenance and transportability. The forward section should contain the optics package and the aft section, the seat, consoles and HOTAS controls as shown in Figure 65.

Optics Package

The optics package should be a pallet assembly, containing the visual and tactile systems. Casters are attached to the base. The width and length of the optics package will be dictated by existing hardware but the shape of the sides, formed by ribs and bulkheads, should simulate the shape of an advanced fighter. The sides of the optics package must be easily removable for equipment installation and maintenance purposes. A simulated canopy sill will establish the upper frame line.

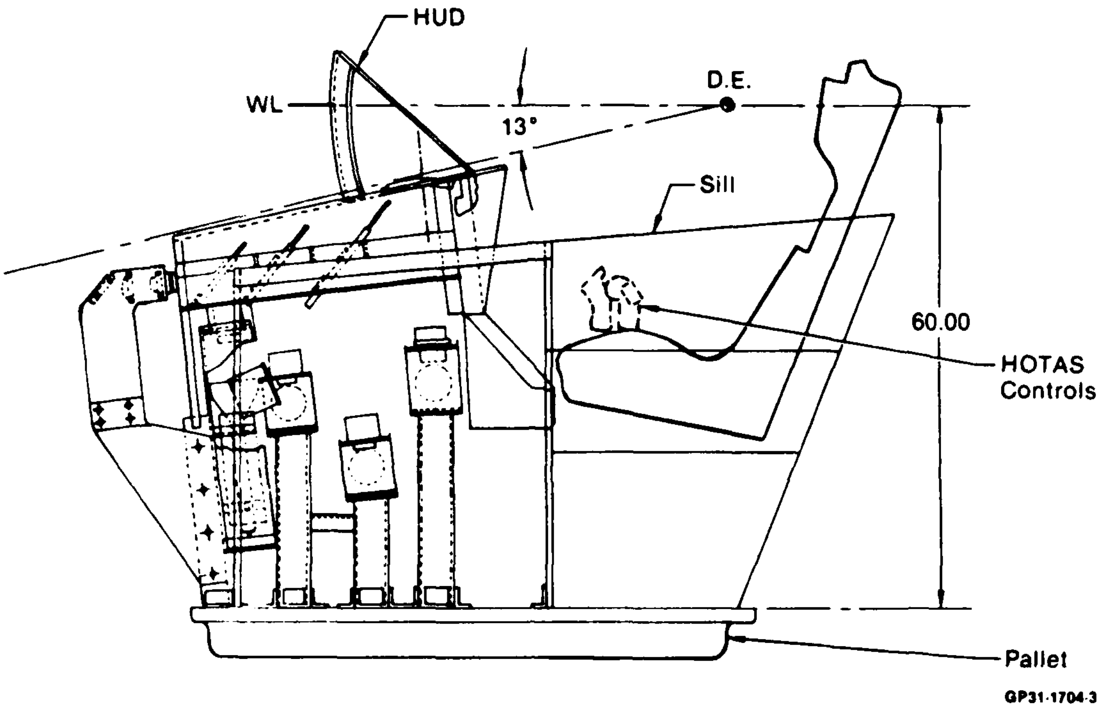

Figure 65. Cockpit Design

The visual systems should be initially assembled and aligned in units as follows:

1) Touch/Display Panel - Three dichroics, touch panel and projection screen as shown in Figure 66.
2) Head Up Display (HUD) - Mirror, beam splitter and projection screen.
3) Map Display - Background map projector, light and mirror as shown in Figure 67.
4) Green CRT and optics
5) Red CRT and optics
6) Blue CRT and optics
7) HUD CRT and optics
8) EO/IR CRT and optics
9) SAR CRT and optics

The units should then be assembled and aligned in the optics package. The touch screen is then attached to the display panel.

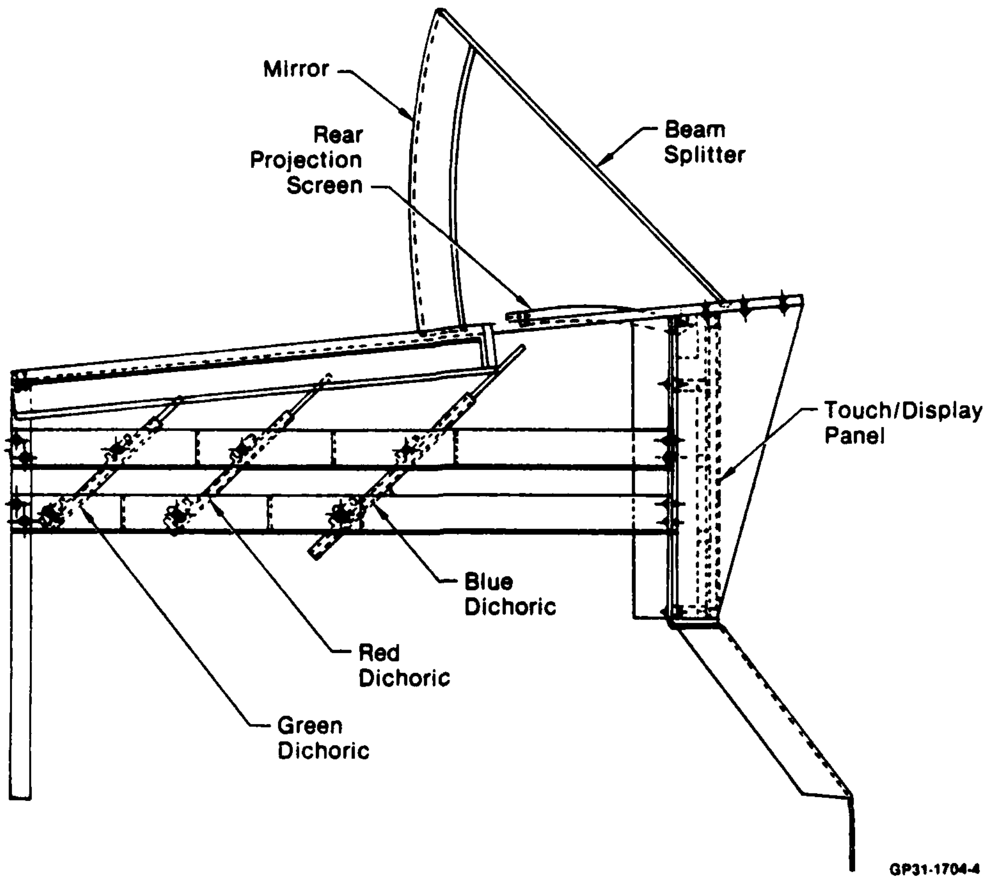

Figure 66. HUD and Touch/Display Panel

A quartz lamp is required in the map projector. Forced air, directed at the lamp and mirror, is required to prevent damage to the lenses. Ducting must be included in the design to provide the air flow passage.

A disconnect panel is required for the optics package. Both electrical and cooling air disconnects must be provided.

Deflection amplifiers are required for the HUD and color CRTs. These CRTs and deflection amplifiers must be positioned close together to prevent loss of display quality.

The color and HUD CRTs and their respective optics may be packaged typically as shown in Figure 68. Adjustment features should be built into the chassis for

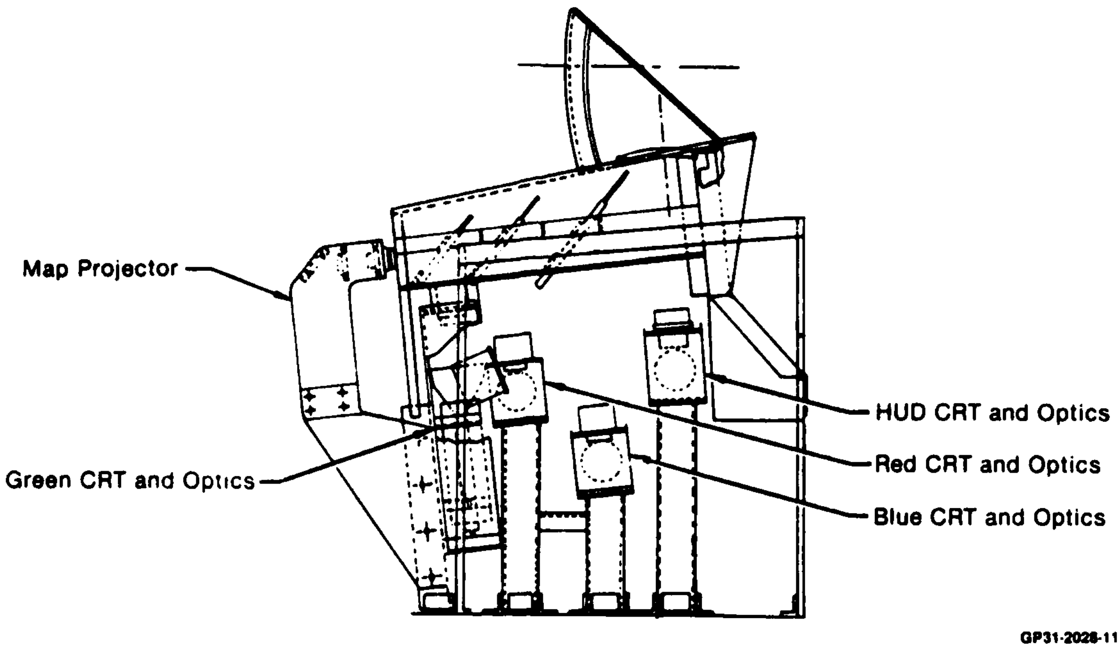

Figure 67. Map Display

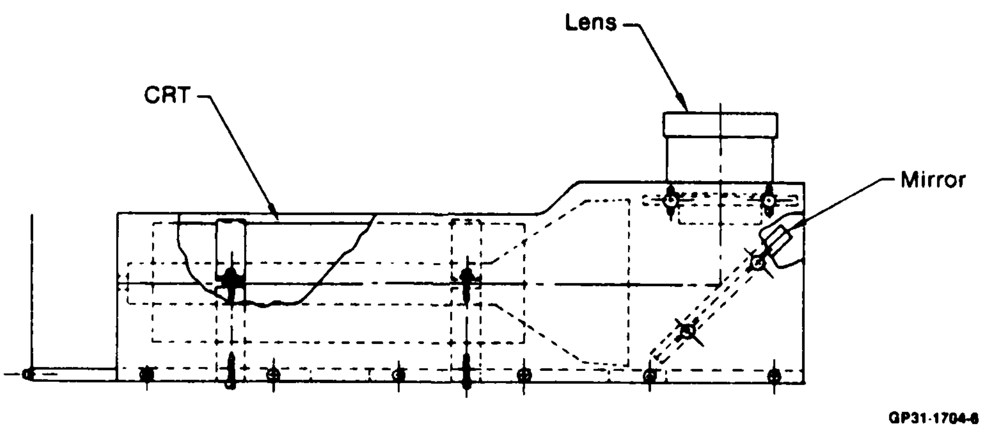

Figure 68. Typical CRT/Optics Chassis

aligning the CRT, mirror and lens. The chassis can be held in position by pedestals mounted on the pallet.

Synthetic Aperture Radar (SAR), Electro Optical (EO), Infra Red (IR) and other sensor displays can be demonstrated with two CRT/optics units mounted on the left and right sides of the optics package as shown in Figure 69. The left side unit can be servo driven vertically so that data can be displayed, on the display panel, in any position from left top to left bottom. The CRT can be mounted on rails and servo driven to focus the display when moved from one position to another. The right side unit is fixed and data is displayed only on the lower right part of the display panel.

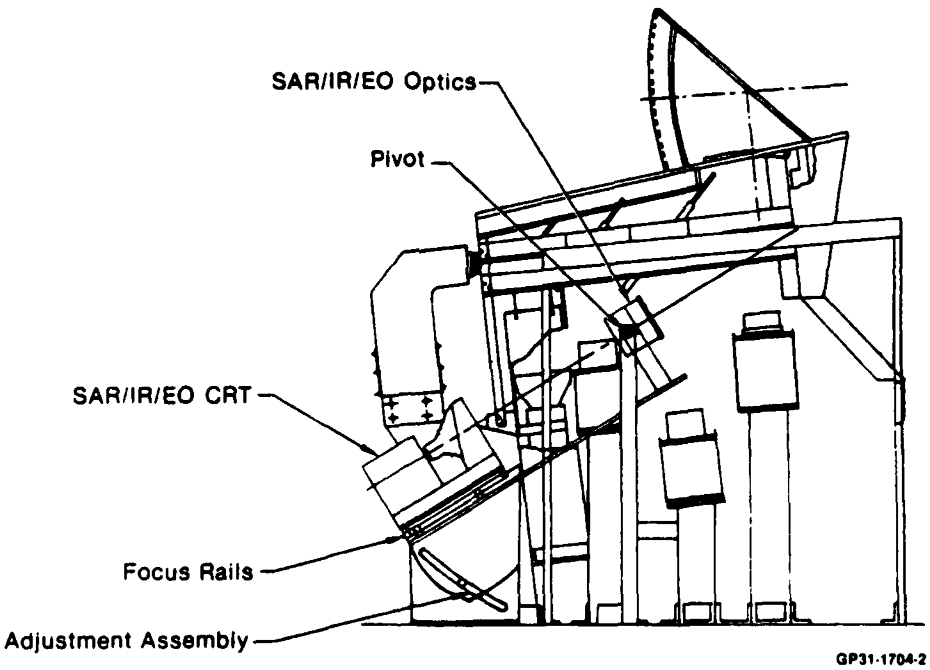

Figure 69. SAR/IO/EO Display

The center panel, below the touch/display panel, is designed for standby instruments. Typical standby instruments, such as altimeter, airspeed, ADI, clock, and vertical velocity may be non-functional simulations. An arrangement of these instruments is shown in Figure 70.

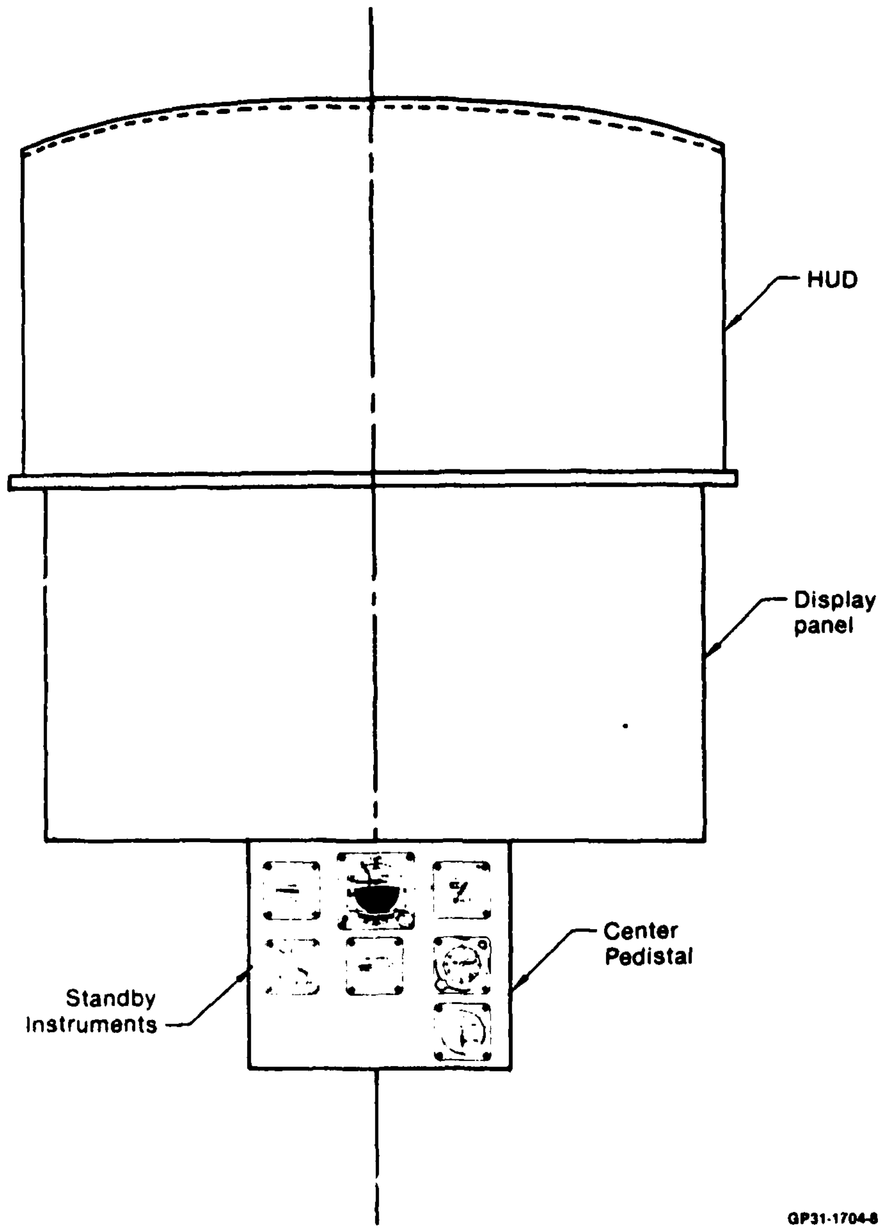

Figure 70. Standby Instruments

Aft Section

The aft section of the cockpit must mate with the optics package and mount on the same pallet as the optics package. A metal and plywood frame can house the seat and consoles. The ejection seat can be mounted on the aft bulkhead. The seat should be positioned so that the design eye point is in correct geometric relationship with other major points in the cockpit, such as the stick and throttle neutral reference points, consoles and display panel. Consoles should have aircraft dzus rail structure so that a side stick-controller and control panels can be easily installed and removed. A communications control panel should be positioned on the left hand console. A sketch of a control panel is shown in Figure 71. A throttle quadrant is designed into the left hand console. The throttle grips and throttle position must be functional. The grip functions were shown in Figure 30.

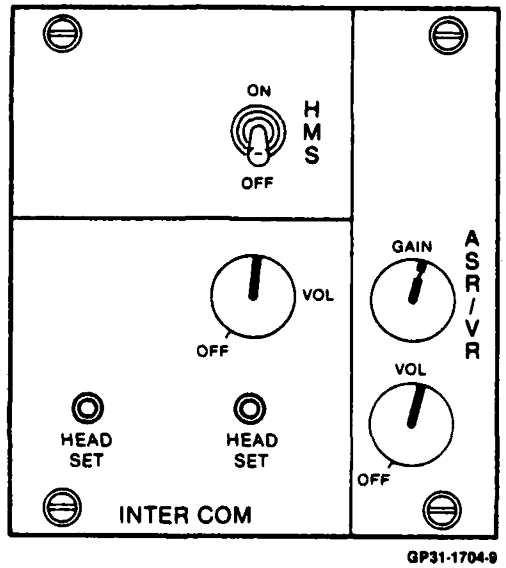

Figure 71. Com Control Panel

An F-18 stick-grip should be installed on a force gage side stick-controller. The side stick can also be positioned as a center stick if dictated by aircraft design. The stick grip should be functional, as was shown in Figure 29. The strain gages sense the lateral and longitudinal input forces and transmit these signals through amplifiers to the input/output unit.

An electrical disconnect panel should be located in the aft cockpit section. This disconnect panel, and the optics package disconnect panel, will then interface the cockpit with a real time input output device, graphics generator, video and power sources.

4.6.2 Cockpit Arrangement - Basic cockpit dimensions and design points are shown in Figure 72. The HUD and display panel command a prominent position in the forward view of the cockpit. Anthropmetric requirements are satisfied in the positioning of the design eye, side stick neutral reference point, throttle neutral reference point, display panel and consoles relative to the seat neutral reference point. An external vision plot of the DTACS cockpit is shown in Figure 73. The vision plot shows a comparison between the DTACS and the F-15. The F-15 is shown in dashed lines.

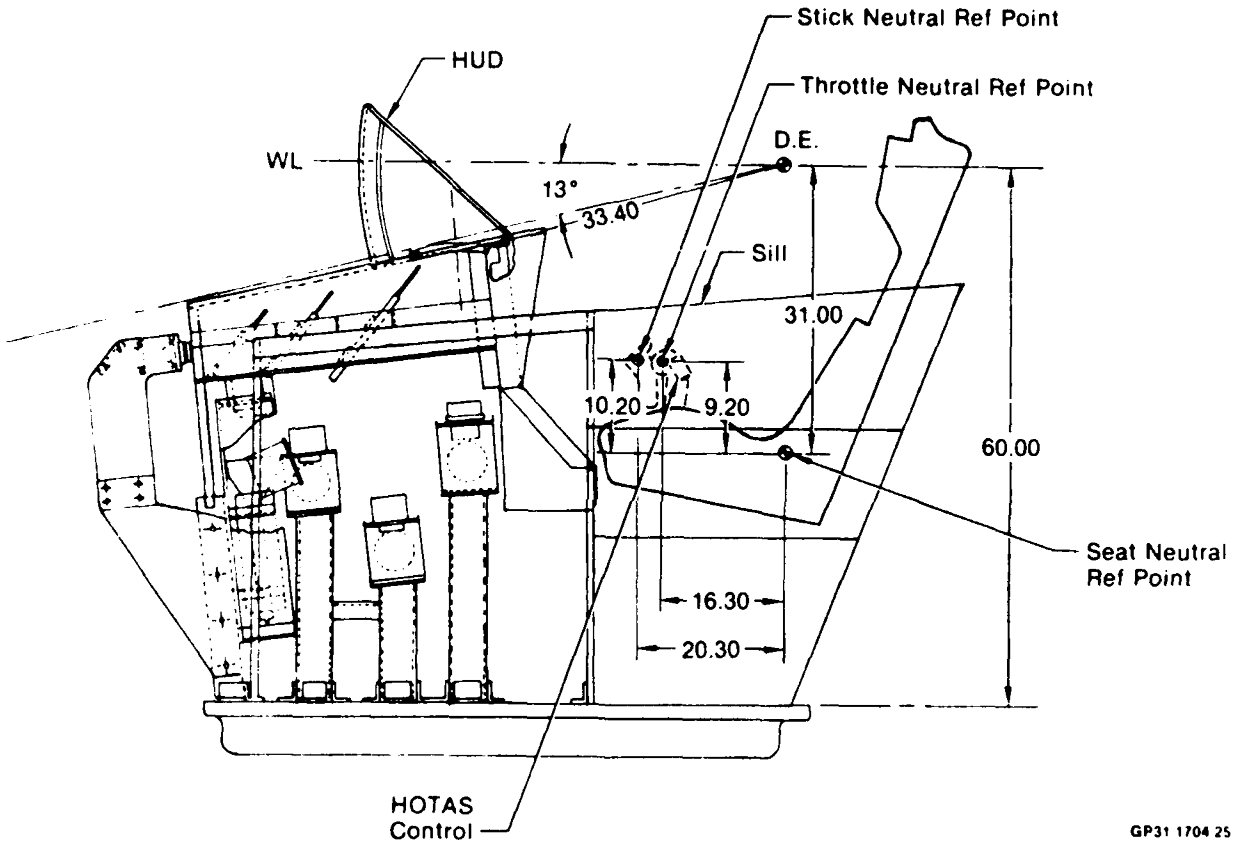

Figure 72. Cockpit Arrangement

4.6.3 Long Lead Items - The following long lead items are recommended for the advanced display techniques demonstrator. A long lead item is defined as taking three months or more from initiation of purchase to receipt of the item. All of the items, are presently available to the MCAIR flight simulation department.

Part Name	Part Number	Quantity	Estimated Lead Time - Months
Touch panel	P0Z30056	1	7
HUD CRT	6M201P53	1	6
Blue CRT	6M201PT500M	1	6
Red CRT	6M201P56	1	6
Green CRT	6M201P53	1	6
Beam Splitter - HUD	P0F32759-5	1	7
Map film transport	2797018-0	1	18
Blue dichoric	90-500	1	4
Red dichoric	90-700	1	4
Green dichoric	90-580	1	4
Stick grip	9020011200-1S	1	12
Throttle quadrant	68A582000-1035	1	18
Voice rec./respon.	VRT111/VTM150	1	3
CIG	CT5 (Typical)	1	20
RTIO	T-080301	1	12
Helmet mounted sight	SHMS-3A	1	5
Computer	CIBER 170	1	24

4.7 CONCEPT DEVELOPMENT AND EVALUATION PLAN

The DTACS Concept Development and Evaluation Plan, as shown in Figure 74, presents a four phase approach. During the current phase, Phase I, a definition study was performed to define the problem and potential solutions, and to formulate the demonstration program requirements.

The Phase I defined problem, a lack of situational awareness, is caused mainly by the use of several small display units in a small cockpit area and the ever increasing amount of data available to the pilot for his evaluation. The results of Phase I proposes to use a large format display in the cockpit to present fused data to the pilot. The technology necessary to solve this problem is currently in its infancy, but two approaches, the single crystal CRT and the projection liquid crystal show promise if funds can be expeditiously applied to their development.

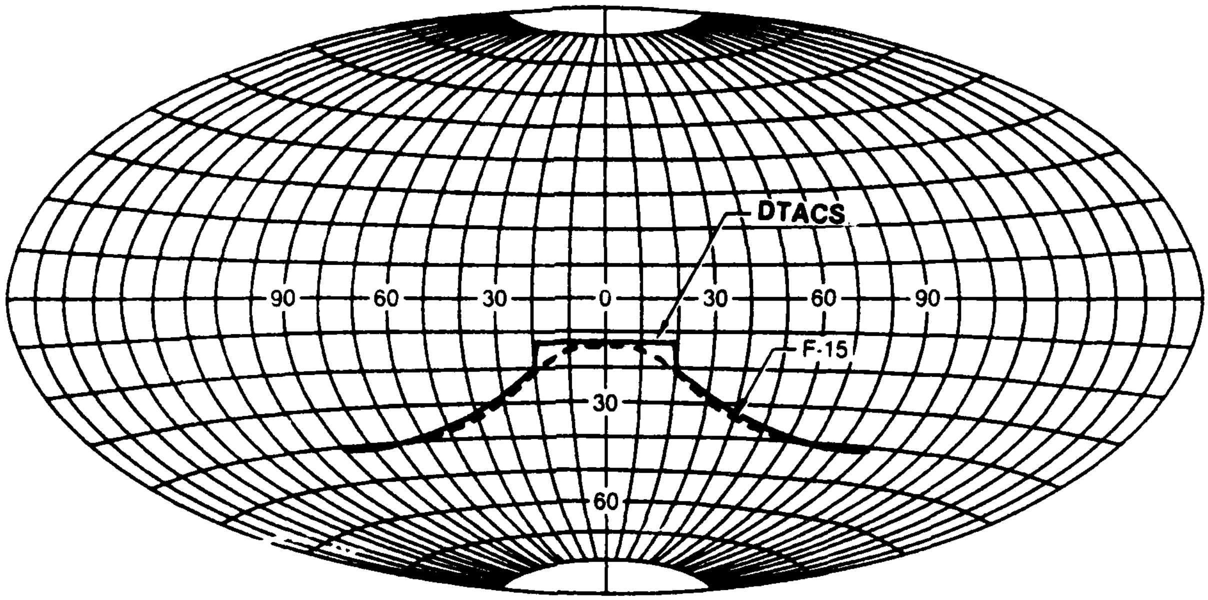

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Figure 73. External Vision Plot

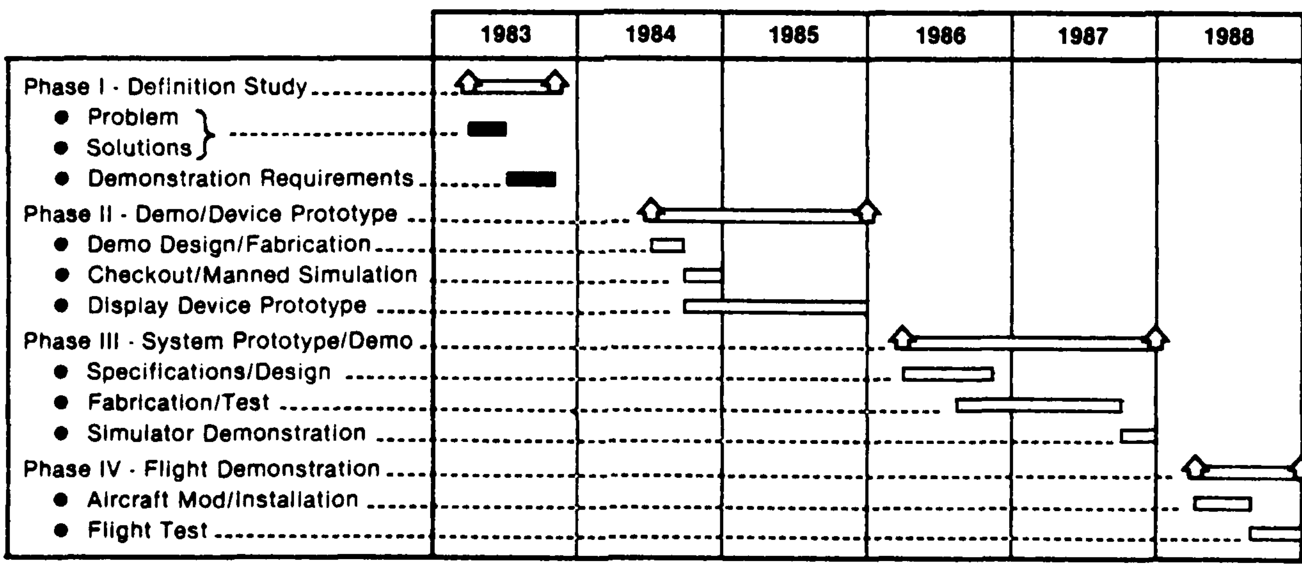

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Figure 74. DTACS Concept Development and Evaluation Plan

The demonstration requirements determined during Phase I address the configuration of the demonstrated device, the data bases needed for the demonstration and simulation facility requirements necessary to demonstrate a large area, high resolution fused display.

Phase II will demonstrate the concept in a simulation environment and will build prototype display devices. A demonstration system will be designed, fabricated, installed and checked out in a manned flight simulation facility to allow pilot evaluation of the advantages of unprecedented situational/awareness. This demonstration system may not necessarily utilize the hardware selected for further development. During this phase the most promising display device technologies will be designed and fabricated to demonstrate the core requirements of brightness, resolution, contrast and producibility.

Phase III will consist of a system prototype demonstration of the most promising technology(s) from Phase II. Specifications and designs for a 12 inch by 12 inch high resolution, high brightness full color flyable display unit. The unit will be fabricated and bench tested, and then installed in the manned flight simulator for further evaluation before being flight tested. The unit will be sized to be installed in the aft crew station of an F-15 sized aircraft.

Phase IV will be a flight demonstration of the system developed in Phase III. A test aircraft will be modified to accept the 12 inch by 12 inch display system in the aft cockpit, and then flight tested. During the flight test, displays will be generated and the display unit will be evaluated in the high ambient conditions of a cockpit. The formats would be generated by onboard sensors, or prerecorded and played back during the flights.

5.0 CONCLUSIONS

The single most pervasive, unrelenting problem in today's tactical aircraft is a lack of situational awareness due to the immense data available and the lack of large area displays on which to "fuse" that data. The DTACS study results show that "unprecedented situational awareness" can be provided by a large format display that is approximately ten times the area of present displays. This large area allows the designer to present the pilot with the "Big Picture" of his current combat situation.

The technical risks associated with developing the DTACS concepts through to fruition in flight hardware are acceptable and are discussed in the following subparagraphs:

5.1 DISPLAY GENERATION

Display generation is a needed technology development. Achieving the brightness, resolution, color, contrast and image size required for the aircraft environment has low technical risk if sufficient resources are committed. Ambient illumination in the cockpit can range from 10 to 70,000 LUX. Cockpit displays based on small color cathode ray tubes with appropriate sun filters have already demonstrated their advantages over electromechanical instruments. Improvements in the brightness, resolution and life of the color CRT has resulted in its extensive use in new aircraft instrument designs. Evaluation of the performance of these new CRTs/filters show that their advantages far outweigh any technical risks associated with their use, i.e., cost, weight, reliability, maintainability etc.

The DTACS concept is based on a large touch sensitive display screen that occupies all or most of the instrument panel area. The current trend for cockpit display development is clearly to push for larger direct view high resolution CRTs or to mosaic several displays. The mosaic approach would seem to offer the least technical risk for the DTACS development. Projection CRT technology employing monolithic crystal screens, Liquid Crystal light valve technology and flat panel devices including both emitter (luminescent, LED, EL, etc.) and nonemitter (passive, L.C. etc.) have the potential for lower weight, power and cost advantages in the DTACS application. Liquid crystal projection is the current leading technology, but other technologies such as projection CRTs with monocrystal faceplates are also promising. Passive L.C. display devices are being developed for use in consumer electronics. Portable television receivers and computer terminals are available with L.C. displays for use in direct sunlight. Both monochrome and color displays are being developed that employ matrix pixel addressing.

Regardless of progress on a flight design, the means for simulating the DTACS concepts at lower ambient light levels is readily achievable. Through existing CRT technology and an appropriate facility such as the Advanced Manned Air Combat Simulator, the DTACS concepts can be developed and evaluated in parallel with or in advance of flight hardware.

5.2 IMAGE GENERATION

Image generation represents a low to medium developmental risk factor for the DTACS flight hardware. This risk is associated primarily with achieving a small physical size for the airborne image generation electronics. However, no similar size problem exists for the simulation equipment. The requirements for stroke and raster image generation can be easily accommodated through existing or advanced computer generated imagery simulation hardware. The simulation peril here is a chance of exceeding that which is feasible for flight hardware.

The image generation technology has high commercial payoffs and therefore is being vigorously pursued by other research and development activities. The DTACS program should reap the benefits of this activity in ways that are as cost-effective as they are technologically dramatic. Size reductions are clearly evident in new computer graphics equipment and low cost CGI is becoming available on the commercial market. Within the next five years, the risk associated with image generation should drop to low or even none.

Assessment of the risks associated with developing the necessary image generation equipment, indicates that minimal technical risk exists, with only a need to closely monitor experimental designs to insure that the flight hardware development is feasible.

5.3 AUTOMATIC SPEECH RECOGNITION

Automatic speech recognition has a medium developmental risk, but places no restrictions on the DTACS program, since DTACS can be developed without ASR. ASR is a relatively new and highly promising technology for providing a "hands free" direct voice command input for the pilot. The potentials for reduction in pilot work load and the viability of the concept are being tested in flight programs (AFTI F16) and in the MACS laboratories during the Radar Aided Mission/Aircrew Capability Exploration (RAMACE) study. The risk for ASR is that achieving a recognition score that approaches 100% is currently only possible in a controlled environment. Background noise, microphone position and changes in the pilots voice due to stress or other factors can seriously affect the recognition scores. Most systems currently available are "speaker dependent". This means that each user must train the system with his or her voice pattern. Further, some means must be provided to load the users pattern each time that person wishes to use the ASR equipment.

Current systems are not able to recognize continuous speech but instead require single word or speech pattern inputs of 1 to 3 second duration.

Continuous speech recognition and speaker independent ASR systems are under development. The driving force for these efforts is the commercial applications for the ASR devices. The DTACS program would benefit from these efforts. The use of ASR could be planned initially as a secondary rather than a prime control method. Prime control inputs by the pilot should be by control switches, HMS, HOTAS or by touch.

ASR therefore represents a medium risk since its use will be adapted to the current capabilities/limitations of the technology.

5.4 VOICE WARNING/RESPONSE TECHNOLOGY

Voice warning/response technology is a no risk item for the DTACS program. It is already in use on the F-15 and F/A-18A. VR technology continues to advance, with several manufacturers offering a variety of new techniques and equipment.

Systems for generating speech include digitized speech or voice playback, various encoding or compression techniques, and voice synthesis. These systems provide speech quality ranging from that indistinguishable from a real human voice to that which is least "natural" with problems of intelligibility for the inexperienced listener. These systems have had extensive application from weather advisories, caution and warning systems, recorded phone messages, to childrens toys. Any of these systems could be used in the DTACS voice response application. However, MCAIR has developed a voice playback system that can simulate (by digital recording) any of the available systems. The voice characteristics can be made distinctive "i.e., computer like", if desired, and simultaneously highly intelligible. These attributes are very desirable for pilot recognition, i.e., that the voice he is hearing is that of the VR system and not chatter on the voice com. MCAIR is in the process of integrating this voice response unit into a ground controlled approach (GCA) voice simulation for the AV-8B program.

This voice response unit will greatly enhance the DTACS simulation and is planned for later use in the program.

5.5 TOUCH PANEL TECHNOLOGY

Touch panel technology represents a low risk factor. Several techniques have already been developed for commercial use that can be adopted for this application. These include transparent conductive films, surface acoustic wave, infrared sources/photo diodes, and surface impedance sensing devices. Any of these techniques might be used. However, the large panel size and flight environment required by DTACS suggest that the infrared technique is preferred. Past experience has shown that the infrared technique has low maintenance, good reliability, can be used with gloves, and can be manufactured in the large screen size required.

5.6 HELMET MOUNTED DISPLAY/SIGHT

Helmet Mounted Display Sight requires a means for accurately sensing helmet position and measuring the helmet's line-of-sight to a target in relation to the airframe. Two techniques have been developed to provide this capability, an infrared source/photo diode sensor and an electromagnetic source/sensor technique.

Either of these techniques might be used to fulfill the program requirements. Both devices have been used at MCAIR in previous flight simulation IRAD programs and both have been successfully interfaced with the flight simulation host computer. The electromagnetic approach is light weight and is compatible with chemical, biological and radiological gear.

Both militarized and commercial units are available of the electromagnetic type and a commercial unit is planned for DTACS prototype development. This is a low risk item.

5.7 RISK SUMMARY

Development of the DTACS concepts for flight hardware will require the heaviest effort in the display device technology area. A laboratory facility (such as MACS) to simulate proposed experimental designs will enable concept development and testing before flight.

It is felt that the payoff of a large format "Big Picture" type display is high enough to the pilots of future aircraft and as the Advanced Technology Fighter in terms of "unprecedented situational awareness" that aggressive development of the necessary technologies and human factor issues should be pursued. The development program outlined herein will provide an orderly achievement of that goal.

6.0 BIBLIOGRAPHY

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LIST OF ABBREVIATIONS AND ACRONYMS

AAA	Antiaircraft Artillery
AAMRAAM	Advanced Medium Range Air-to-Air Missile
AAR	Air-to-Air Refueling
AC	Alternating Current
A/D	Analog to Digital
ADC	Analog to Digital Converter
AFWAL	Air Force Wright Aeronautical Laboratories
AGL	Above Ground Level
AOA	Angle of Attack
ARIP	Air Refueling Intercept Point
ATR	Automatic Target Recognizer
AWACS	Airborne Early Warning and Control System
BVR	Beyond Visual Range
CAP	Combat Air Patrol
CAS	Close Air Support
CGI	Computer Generated Imagery
CIC	Close In Combat
CPU	Central Processing Unit
CRT	Cathode Ray Tube
D/A	Digital to Analog
DAC	Digital to Analog Converter
DMA	Direct Memory Access
DNT	Dual Mode Tracker
DTACS	Display Techniques for Advanced Crew Stations
ECM	Electronic Countermeasures
EIA	Electronic Industries Association
EL	Electroluminescent
ENG	Engine
EO	Electro-Optical
EPROM	Electrically Programmable Read Only Memory

EW	Electronic Warfare
FEBA	Forward Edge of Battle Area
FLIR	Forward Looking Infrared
FLIR	Forward Looking Infrared
FLR	Forward Looking Infrared
GAAS	Gallium Arsinide
GMTD	Ground Moving Trget Detection
GMTI	Ground Moving Target Indicator
GR	Graphics
GRS	Global Positioning System
HDD	Head Down Display
HMD/S	Helmet Mounted Display/Sight
HOTAS	Hands On Throttle And Stick
HSD	Horizontal Situation Display
HUD	Head-Up Display
I^2R	Imaging Infrared
I/O	Input/Output
IFFC	Integrated Flight Fire Control
IIR	Imaging Infrared
IP	Initial Point
IR	Infrared
IRAD	Independent Research and Development
IRSTS	Infrared Search and Track System
JTIDS	Joint Tactical Information Distribution System
KHz	Kilo-hertz
LC	Liquid Cyrstal
LCD	Liquid Cyrstal Display
LE	Luminous Efficiency
LED	Light Emitting Diode
LSI	Large Scale Integration
LST	Laser Spot Tracker

LIST OF ABBREVIATIONS AND ACRONYMS (Cont'd)

$\overline{M}$	Million
M	Mach
MACS	Manned Air Combat Simulator
MAS	Maneuvering Attack System
MCAIR	McDonnell Aircraft Company
MDC	McDonnell Douglas Corporation
MIL HDBK	Military Handbook
MIPS	Millions of Instructions per Second
MOSFET	Metal Oxide Semiconductor - Field Effect Transistor
mr	Milliradian
MTBF	Mean Time Between Failure
MTTR	Mean Time To Repair
NAV	Navigation
NM	Nautical Mile
PDP	Plasma Display Panel
RAM	Random Access Memory
RAM/ACE	Radar Aided Mission/Aircrew Capability Exploration
REC	Receiver
RF	Radio Frequency
RGB	Red, Green, Blue
RTIO	Real Time Input/Output
RWR	Radar Warning Receiver
SAAHS	Stability Augmentation and Altitude Hold System
SAM	Surface to Air Missile
SAR	Synthetic Aperture Radar
SAW	Surface Acoustic Wave
SEC	Second
SID	Standard Instrument Departure
SRC	Speech Recognition Control
SYST	System
TA	Terrain Avoidance
TACAN	Tactical Air Navigation

LIST OF ABBREVIATIONS AND ACRONYMS (Cont'd)

TDC	Target Designator Control
TF	Terrain Following
TOC	Tactical Operations Center
TV	Television
TWS	Track While Scan
UV	Ultra-Violet
VGM	Video Graphics Multiplexer
VHSIC	Very High Speed Integrated Circuits
VLSI	Very Large Scale Integration
VR	Voice Response
VRC	Voice Recognition Control
W/	With
WAM	Wide Area Monitor
WEAP	Weapon

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